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A Lockset analysis of farm to plant milk assembly

John Paul Smith
Iowa State University

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John Paul Smith

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CHAPTER I. INTRODUCTION

The country assembly of milk has involved trucks since milk was first picked up in cans. The trucks have always collected milk from the individual farms and delivered it to the milk plant. At first, farmers milked a dozen cows to provide milk for their families, and a weekly or monthly flow of income. Today the era of small herds, cans, and stanchions is giving way to larger herds, pipelines, and bulk tank systems, as well as increasingly important management decisions on the production, the breeding, and the feeding of the dairy herd. One factor that hasn't changed is that the milk is still assembled by trucks and delivered to a milk plant.

Technical developments in refrigeration, storage, and transportation have affected the organization of most dairy marketing industries by increasing the size of both the producing and the consuming areas available to the industry. Even with the new developments in the transportation of fluid milk, the problems of how to increase marketing efficiency and how to lower the hauling costs both to the producers and to the dairy industry still exist.

Preston and Collins (17) have developed four factors to measure in order to evaluate the efficiency of a market.

They are:

1. Viability-stability
2. Cost per unit
3. Revenues of market participants
4. Realization of potential transactions

By viability is meant that the market will continue to exist. Minimizing the marketing margins affects the cost per unit and the revenues of market participants.

The lowering of marketing charges through increased efficiency of the movement of milk will increase the revenues to some market participants. According to Preston and Collins, marketing efficiency would be increased.

Realization of potential transactions deals with exchange efficiency. Any method or tool that could be used to improve the transportation of milk from the producer to the milk plant and from the milk plant to the consumer would lead to an improvement in marketing efficiency.

Improving marketing efficiency is a problem faced by all members of the dairy industry. Strides forward are being taken in many different areas in trying to improve marketing efficiency. This thesis deals with one of these steps. It is called the Lockset Method, and its intended use is to design efficient truck routes for the delivery and/or the collection of transported goods.

The section entitled PROBLEM STATEMENT deals with the general routing problem. The INTRODUCTION TO LOCKSET and MODEL DEVELOPMENT sections show what Lockset is designed to do and how it works. The REVIEW OF THE LITERATURE section shows what has been done previously. The rest of the thesis will deal with an application of Lockset to the

Twin Lakes, Minnesota division of Mid-America Dairymen, Inc. Potential routes will be calculated.

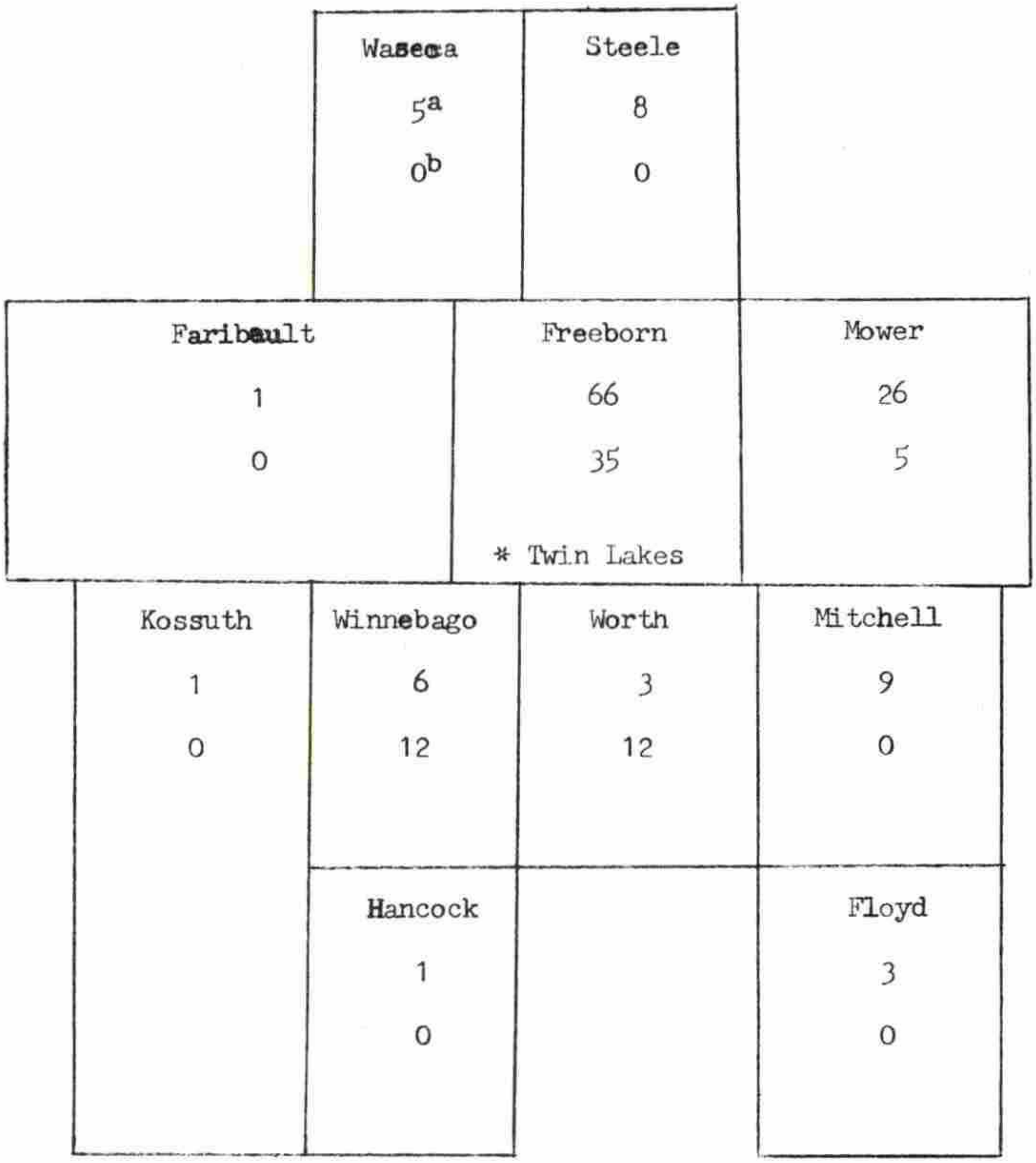
CHAPTER II. PROBLEM STATEMENT

The problem can be stated as designing the truck routes and the sequence of stops for each route to collect all the milk in the given area in the least amount of time while satisfying all the restrictions imposed on the routing solution.

The Twin Lakes, Minnesota, area was chosen after conferring with Mid-America Dairymen officials. The area is small: 6 Grade A routes involving 129 producers and 4 Manufacturing grade routes involving 64 producers. To insure a workable and feasible routing solution with available computing funds, the problem must be relatively small. Figure 1 shows the 11 county production area in which the Twin Lakes milk plant operates. The number of Grade A and Manufacturing grade producers in each county is also shown.

Figure 2 (Grade A) and Figure 3 (Manufacturing grade) show the location of each producer in relation to all other producers in the 11 county production area. Each producer is coded according to his particular route number.

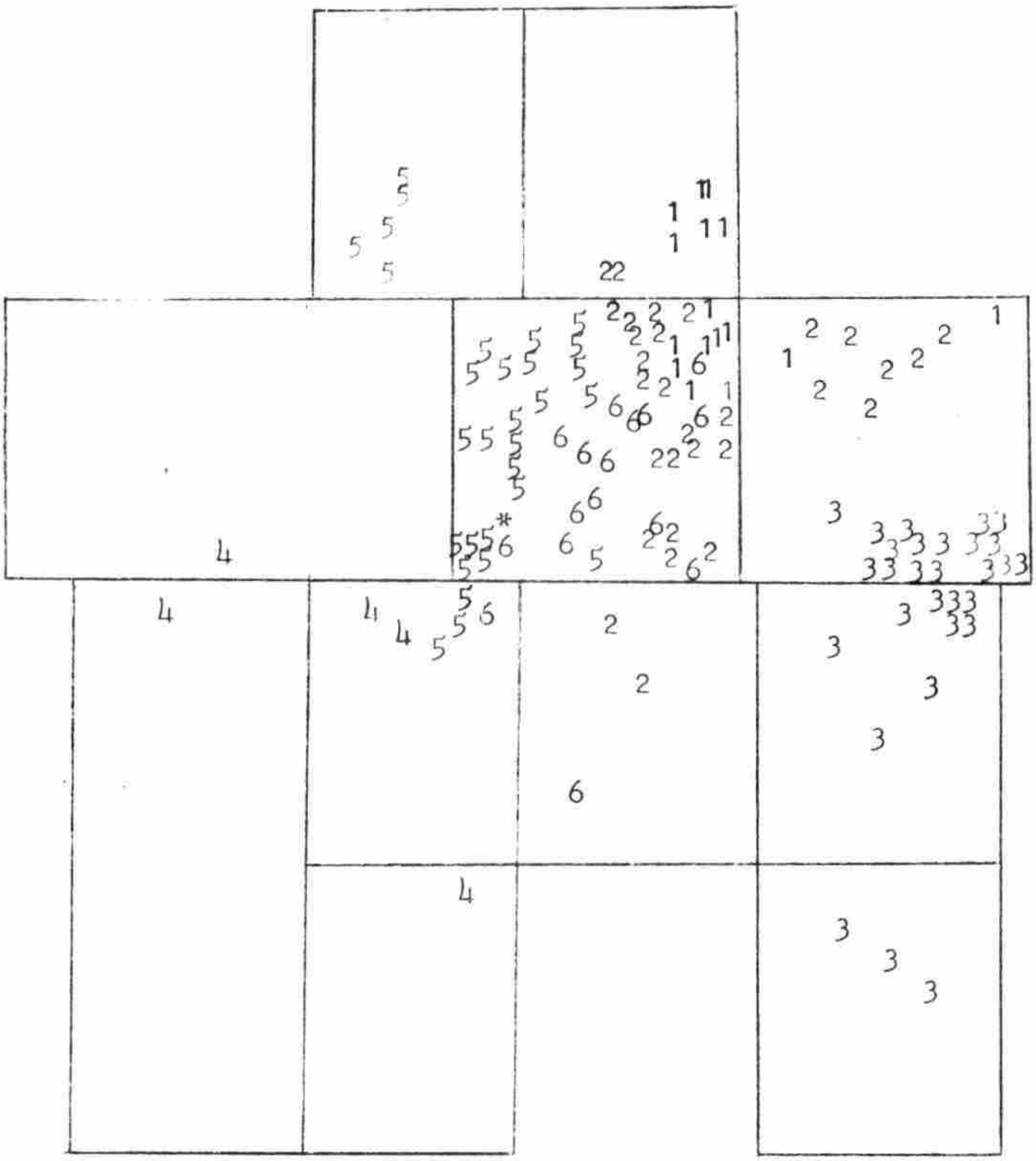
Mid-America Dairymen, Inc. has a marketing area extending from Minnesota to Texas. Each individual area does its own decision making on the routing of trucks in the milk collection process. The truck routes are the result of tradition, merger, or consolidation but not of an optimizing analysis. The Lockset Method is an attempt to add this optimizing aspect to solutions to the truck routing problem.



[a]Number of Grade A producers per county.

[b]Number of Manufacturing grade producers per county.

Figure 1. Twin Lakes production area

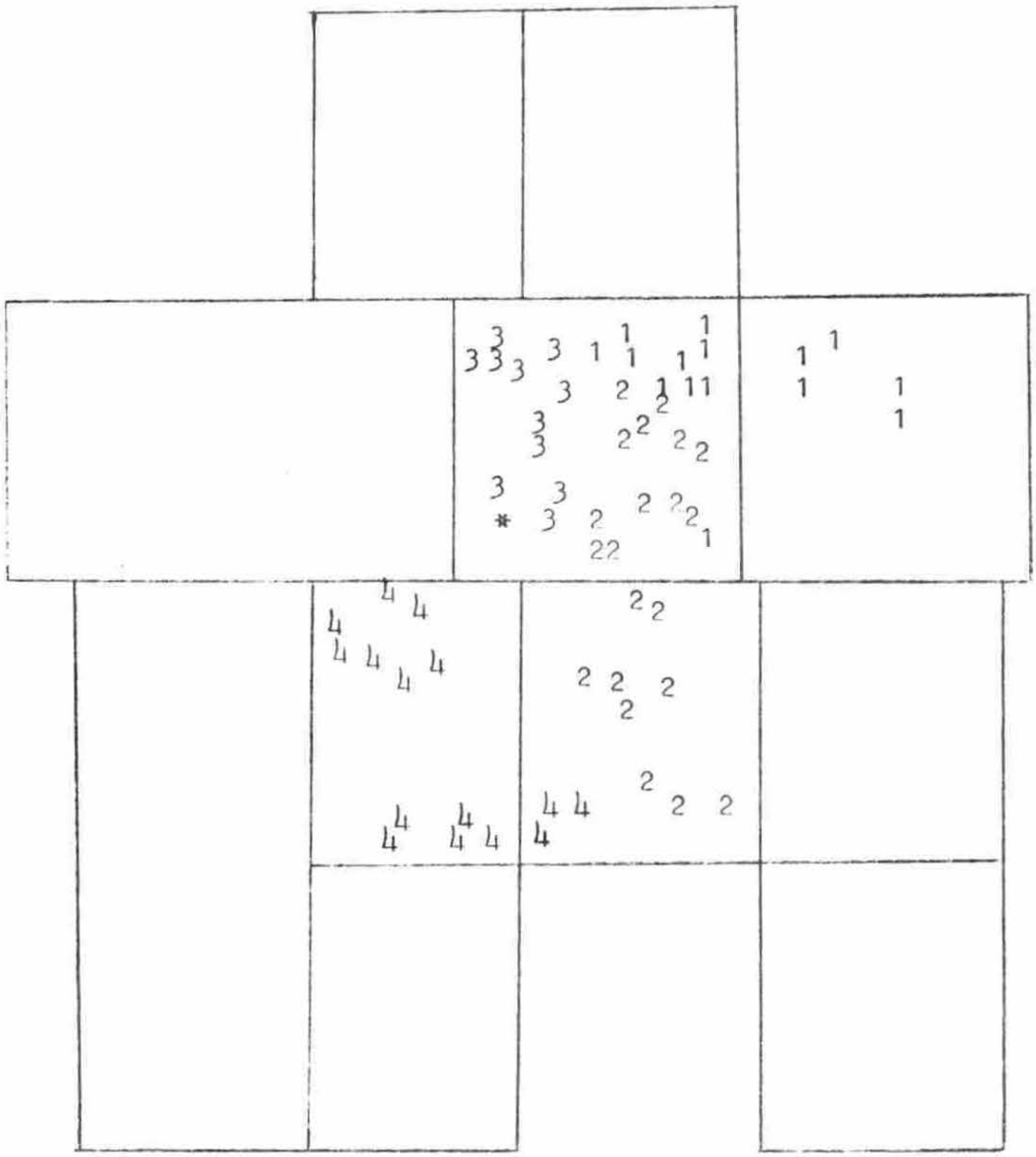


1 = Route 510
2 = Route 511
3 = Route 513

4 = Route 521
5 = Route 522
6 = Toute 523

*Twin Lakes

Figure 2. Location of Grade A producers listed by routes



1 = Route 527
2 = Route 573
3 = Route 577
4 = Route 578
*Twin Lakes

Figure 3. Location of Manufacturing grade producers listed by route

CHAPTER III. INTRODUCTION TO THE LOCKSET METHOD

The Lockset Method is an analytical technique designed to determine an efficient means of either: (a) distributing products from a single distribution center for several customers who may require various amounts of service or (b) collecting products for a single collection center from several customers who may require various amounts of service.

The technique could have numerous applications by firms dealing with farmers such as the delivery and/or pick up of feed, fertilizer, fuel, milk, etc. Our application of Lockset will deal with the hauling of milk from farm to plant.

Lockset can also be applied in other areas such as the routing of school buses, garbage trucks, and other routing situations that meet the Lockset Method's requirements. Lockset can be used to design efficient routes for the distribution and the collection of goods, to reorganize existing routes, and to answer policy questions about the routes.

The data needed for the Lockset Method includes the location of the center plant, the location of the customers to be served, the distances between all pairs of customers, the distance between each customer and the center plant, customer information, truck information, and the conditions or restrictions under which the customers are to be served.

Locations can be plotted on a map or set up with a coordinate system or a node network for computer analysis.

Distance can be measured in minutes, in miles, or in any unit of measurement which can be converted into dollars and cents for comparisons. Customer information needed includes mainly the amount to be delivered or collected. Truck information needed is the number, type, and capacity of the vehicles available, the road network over which the trucks travel, and the number of drivers available to run the trucks.

Schruben and Clifton (19) developed the Lockset Method in late 1968. The method has roots in procedures proposed by Dantzig and Ramser (2) and by Clarke and Wright (1). Being a new research tool, the Lockset Method hasn't had widespread application, but when it has been used the results have been promising. Most published studies to date have been by universities. If additional studies are conducted and the credibility of the Lockset Method rises, then the use of Lockset in the real world should increase.

CHAPTER IV. MODEL DEVELOPMENT

Delivery and pickup by trucks are important activities to many firms. When a single trip involves deliveries to more than one customer, the dispatcher must determine the exact sequence in which the stops will be made. The sequence of stops is important in determining the length of the route and in positioning the load in the truck in order for unloading efficiently. A principal factor in affecting the costs of delivery or pick up is the distance traveled per unit of product delivered or picked up.

Any procedure which will result in driving a shorter distance or spending less time on a route while performing the same services can contribute to lower costs and improved market efficiency. The Lockset Method of truck routing offers considerable promise of being a tool that will greatly aid the dispatcher in solving the routing problem.

One of the alternatives to Lockset the dispatcher faces is to calculate the distance of each possible route and compare the distances. The total number of possible routes for one vehicle traveling through N points and returning to the origin is $\frac{N!}{2}$. A dozen stops will have nearly 240 million different routes.

The Lockset Method is heuristic. The calculated routes are not the result of a mathematical process of optimization. The possibility of a more nearly optimal solution exists.

The Lockset Method provides a feasible-rational solution rather than a feasible-optimum solution. In this sense it should be used as a tool to aid the dispatcher rather than as a substitute method to take the dispatcher's place.

Other problems with the Lockset Method are:

1. Lockset can handle only one center point.
2. The technique is designed to minimize travel time or distance rather than total distribution costs.

Minimizing travel time will generally give a fairly accurate account of distribution costs.

The following are two hypothetical illustrations of the Lockset Method. The first is a simple traveling salesman problem, and the second is a multiple route problem with added restraints. Both illustrations contain graphical explanations.

In the traveling salesman problem, all the delivery stops are given. The problem is to connect the given points in a route having the shortest distance. The following example contains a home plant, P_0, and five customer locations, P_1 to P_5. The Lockset Method starts out by assuming that each customer is served on a one-stop route as shown in Figure 4. This type of routing maximizes the traveling distance.

The distance between the plant and each customer and the distance between each pair of customers is needed for the Lockset Method to work. Table 1 gives the information for this example. Only half of the matrix is needed because the

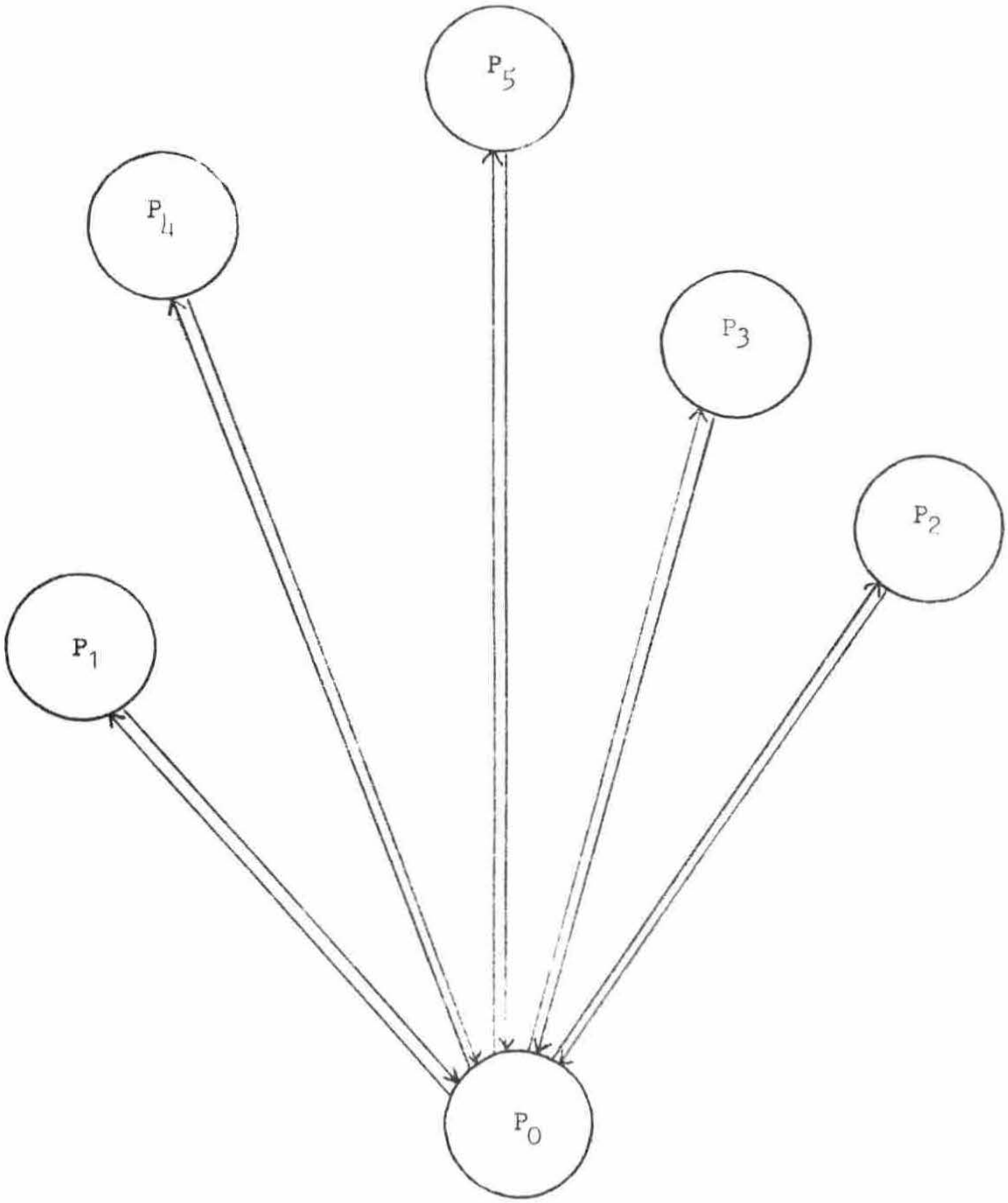


Figure 4. Initial solution to Basic Problem 1

Table 1. Distance matrix for Problem 1 in minutes

To	From				
	P_0	P_1	P_2	P_3	P_4
P_1	20				
P_2	25	40			
P_3	28	42	3		
P_4	31	15	21	12	
P_5	40	22	18	8	10

distances between P_1P_2 and P_2P_1 are the same.

The first step in the Lockset process is to list all the possible pairs of customers. The pair listings are shown in Table 2. The number of possible pairs is equal to a combination of N points taken 2 at a time or $\frac{N!}{2!\,(N-2)!}$. This example contains 5 points which yield $\frac{5!}{2!\,(5-2)!}$, or 10, pairs.

The next stop is to compute the distance saved coefficient which is: $DSC_{ij} = P_oP_i + P_oP_j - P_iP_j$ where:

P_o is the origin
P_i is the customer i, i = 1, 2, ..., 5.
P_j is the customer j, j = 1, 2, ..., 5.
P_oP_i represents the distance between P_o and P_i.
P_oP_j represents the distance between P_o and P_j.
P_iP_j represents the distance between P_i and P_j.

The DSC is the distance saved by servicing two customers on the same route and the calculations of the DSC_{ij} is shown in

Table 2. Pair list and distance saved coeffcient for Problem 1 in minutes

P_i-P_j	P_oP_i	P_oP_j	P_iP_j	DSC_{ij}
P_1-P_2	20	25	40	5
P_1-P_3	20	28	42	6
P_1-P_4	20	31	15	36
P_1-P_5	20	40	22	38
P_2-P_3	25	28	3	50
P_2-P_4	25	31	21	35
P_2-P_5	25	40	18	47
P_3-P_4	28	31	12	47
P_3-P_5	28	40	8	60
P_4-P_5	31	40	10	61

Table 2.

The third step is to consider joining the pair with the largest DSC on the same route. From Table 2 it can be seen that joining P_4 and P_5 on the same route would save 61 minutes. Before this pair can be locked into the route, it must meet the following tests:

1. Each stop must have at least one leg connected with the origin.
2. Each stop must previously have been on a different route.

The pair of P_4P_5 passes the tests and therefore the pair is locked in on the same route. See Figure 5. The next step is to continue searching the pairs, working from the largest DSC to the smallest DSC. Each pair is considered for the route. If the pair meets the tests, it is locked into the route. If the pair fails either test, it is locked out of the route. Figures 4-8 are a graphical view of this process.

Figure 4 shows the 5 separate routes. Pair P_4P_5 has the largest DSC and meets the tests. Figure 5 shows this aggregation. The routes are now $P_0P_4P_5P_0$, $P_0P_1P_0$, $P_0P_3P_0$, and $P_0P_2P_0$. The next largest DSC is for P_3P_5. This pair meets the tests and is joined on the route as shown in Figure 6. The routes are as of now $P_0P_4P_5P_3P_0$, $P_0P_1P_0$, and $P_0P_2P_0$.

Figure 7 shows the 3rd aggregation, the joining of pair P_2P_3. This pair has the next highest DSC. The routes are now $P_0P_4P_5P_3P_2P_0$ and $P_0P_1P_0$. The pair with the next largest DSC is P_2P_5. This pair is locked out of the route for failing test 1 and test 2. P_5 has no leg connected with the origin, and P_2 and P_5 are already on the same route. P_3P_4 is the next pair to consider. It fails both tests. P_3 has no leg connected to the origin, and P_3 and P_4 are already on the same route.

The next pair to consider is P_1P_5. P_5 does not have one leg connected to the origin thus it fails test 1. The pair with the next largest DSC is P_1P_4. This pair meets all the tests and is joined on the route. This fourth aggregation is shown in Figure 8. The route in its final form is

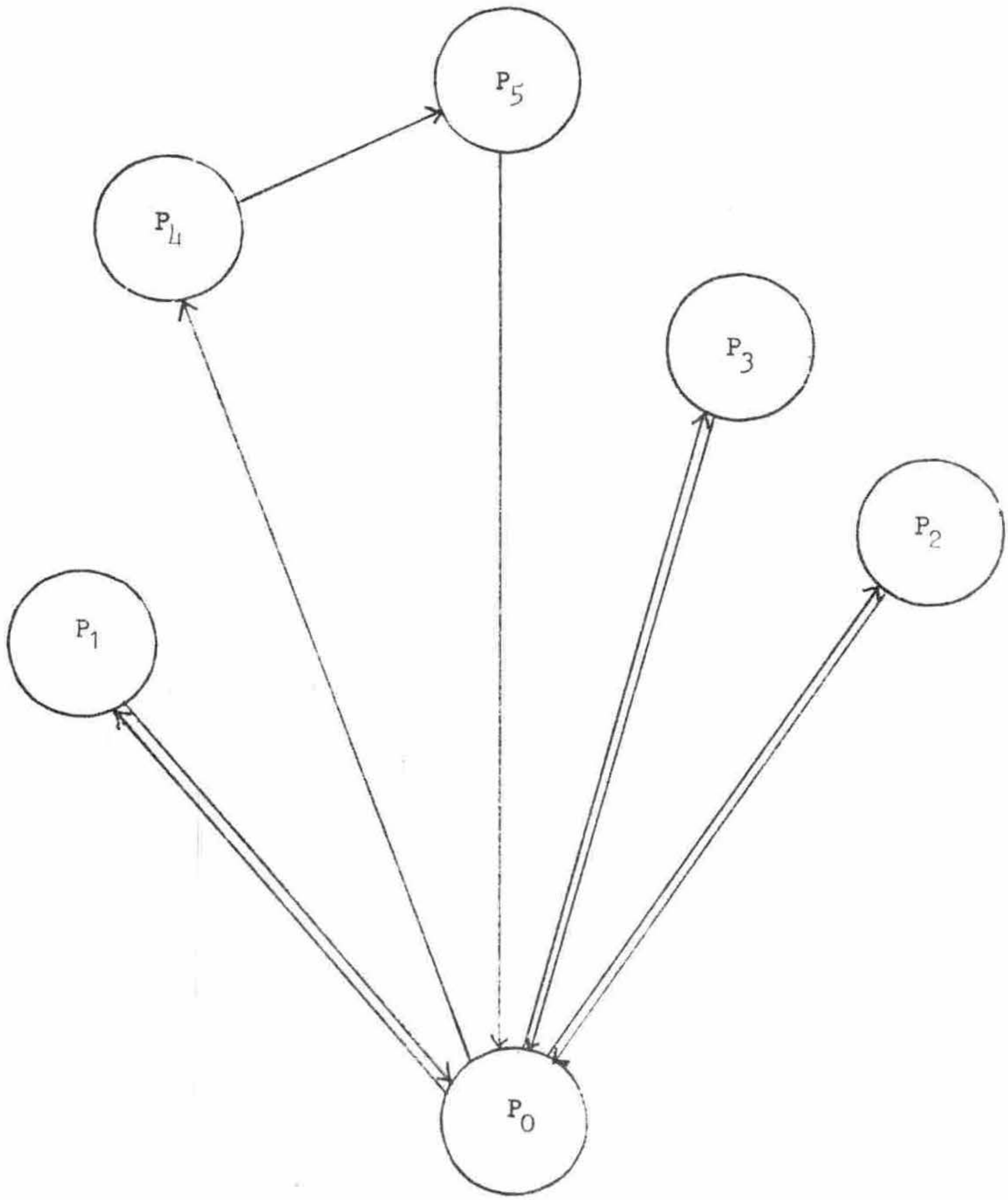


Figure 5. First aggregation, joining P_4 and P_5

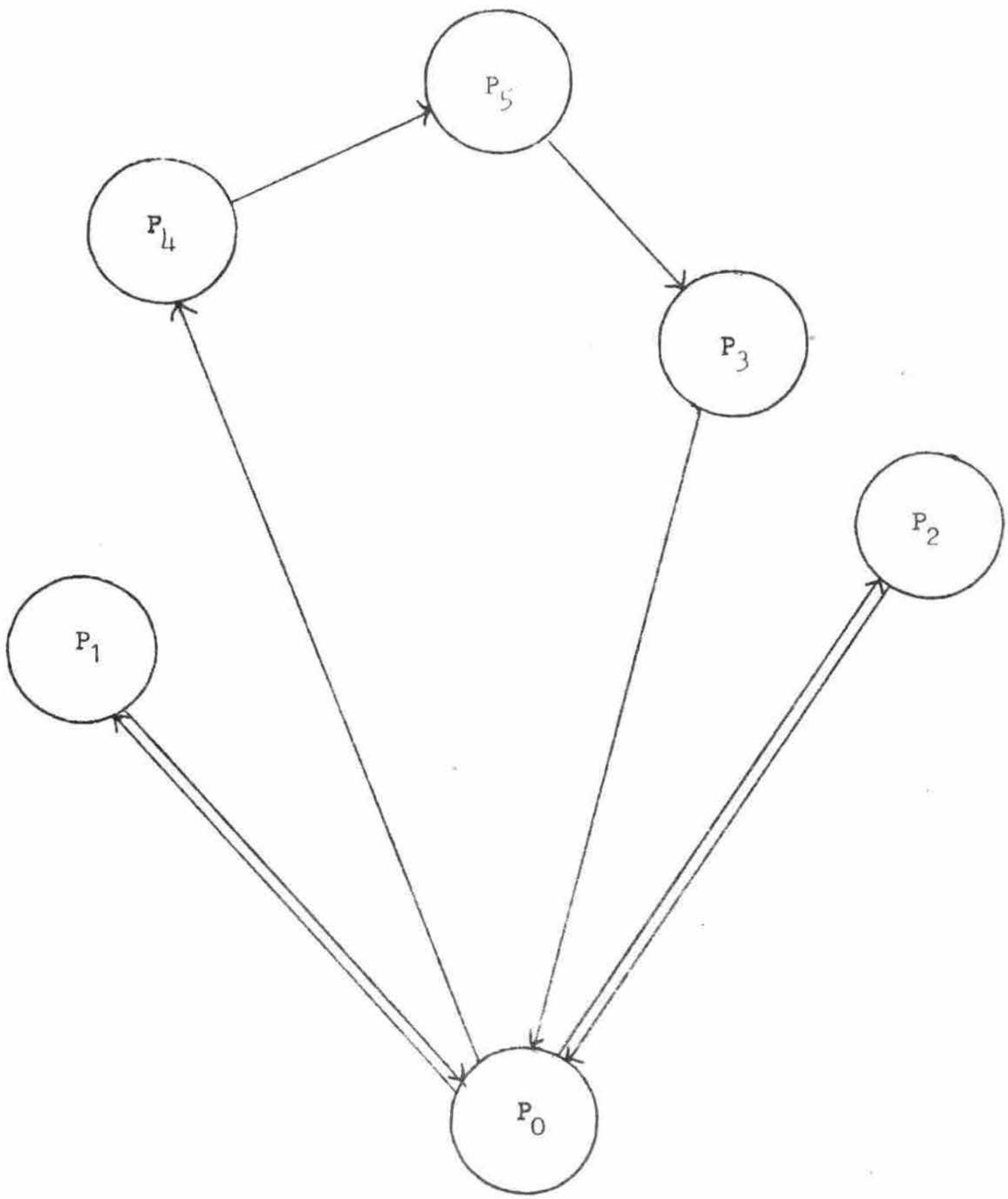


Figure 6. Second aggregation, joining P_5 and P_3

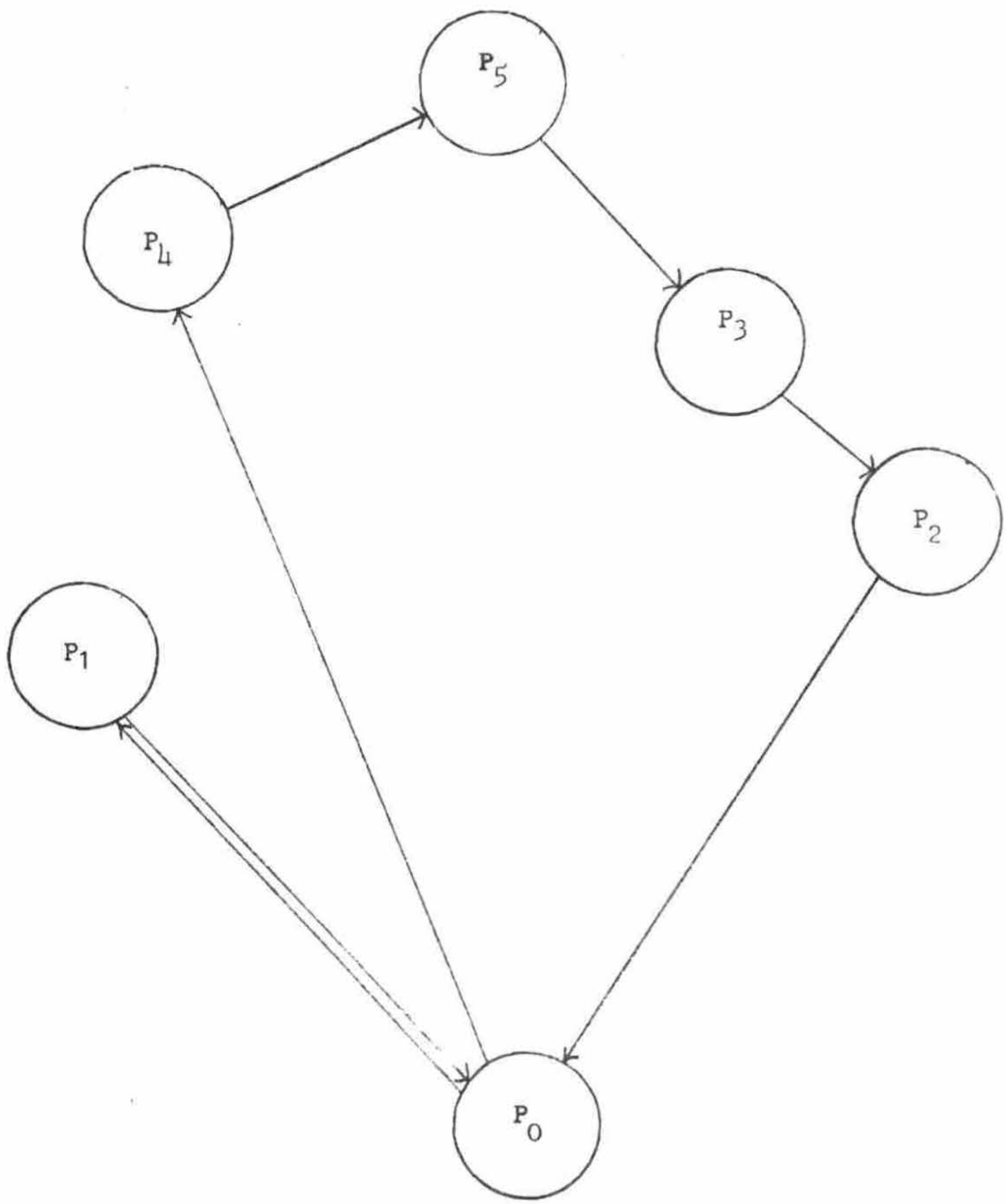


Figure 7. Third aggregation, joining P_3 and P_2

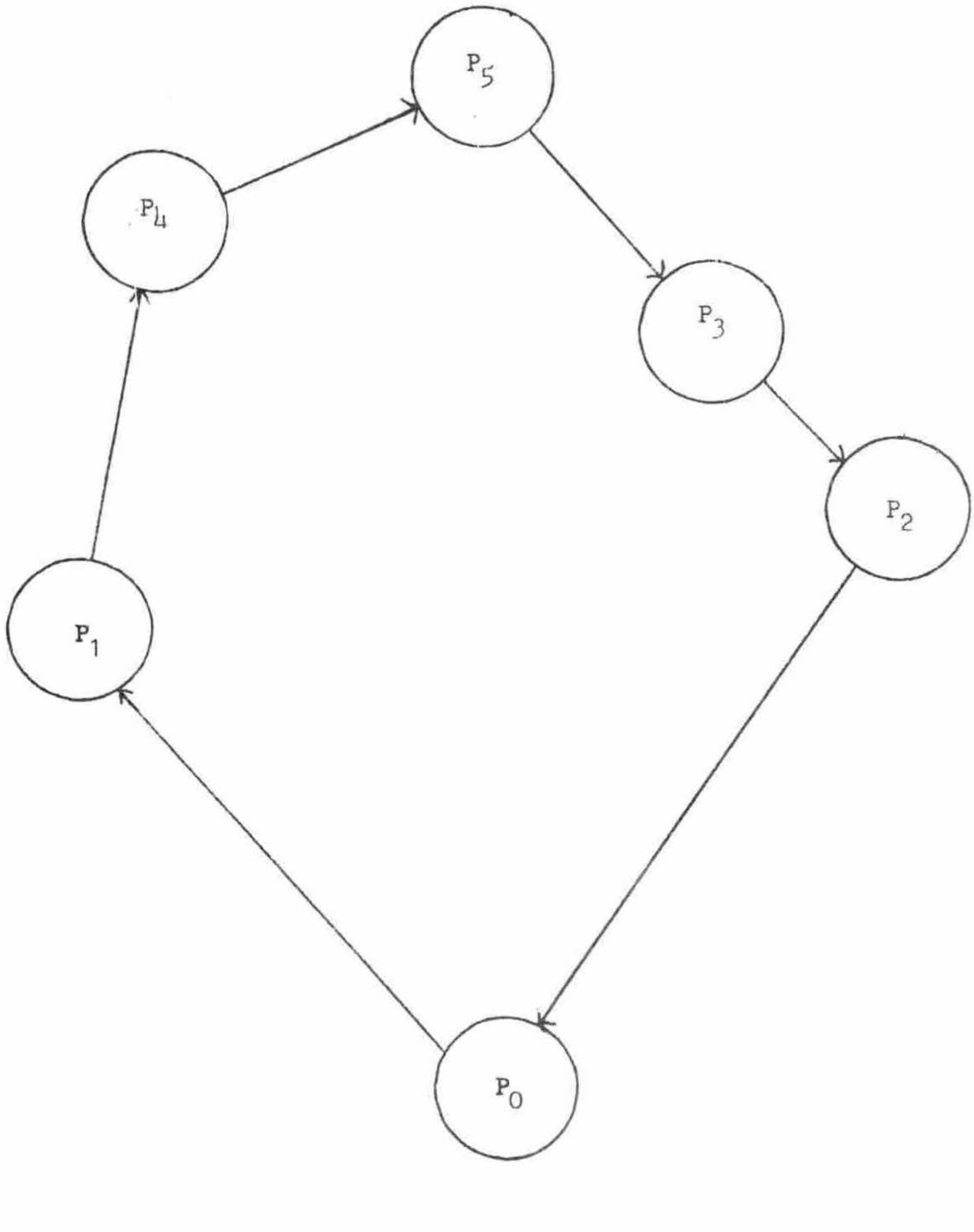


Figure 8. Fourth and final aggregation, joining P_1 and P_4

$P_0P_1P_4P_5P_3P_2P_0$. Pairs P_2P_4, P_1P_3, and P_1P_2 don't need to be tested because the final route is already calculated.

The basic procedure for the Lockset Method has been described in this simple traveling salesman problem. The following is a more complex application of Lockset. It is a multiple route problem with restrictions on the capacity of the delivery units and the amount of time the units can be on the road. It is assumed that the deliveries can't be made in one route. Figure 9 gives the location of the origin, P_0, the location of the customers, P_1-P_5, and the distances in minutes between each point.

The restrictions are as follows: three trucks are available, each with a 10 ton capacity and maximum of 120 minutes for on the road travel time. Stop time at each customer is not considered. The time required to pick up or deliver the requested product at the customer's farmstead is considered stop time. The amounts needed to be delivered to each customer are: P_1 - 4 tons, P_2 - 4 tons, P_3 - 12 tons, P_4 - 6 tons, and P_5 - 3 tons. The amounts needed by customers are subject to change, thus the routes developed by the Lockset Method are subject to change. For this example Lockset will determine the routes and the sequence of stops within each route. The Lockset procedure will tend to minimize the total distance for all the routes.

As in the traveling salesman problem, a distance matrix needs to be set up and the distance saved coefficients need

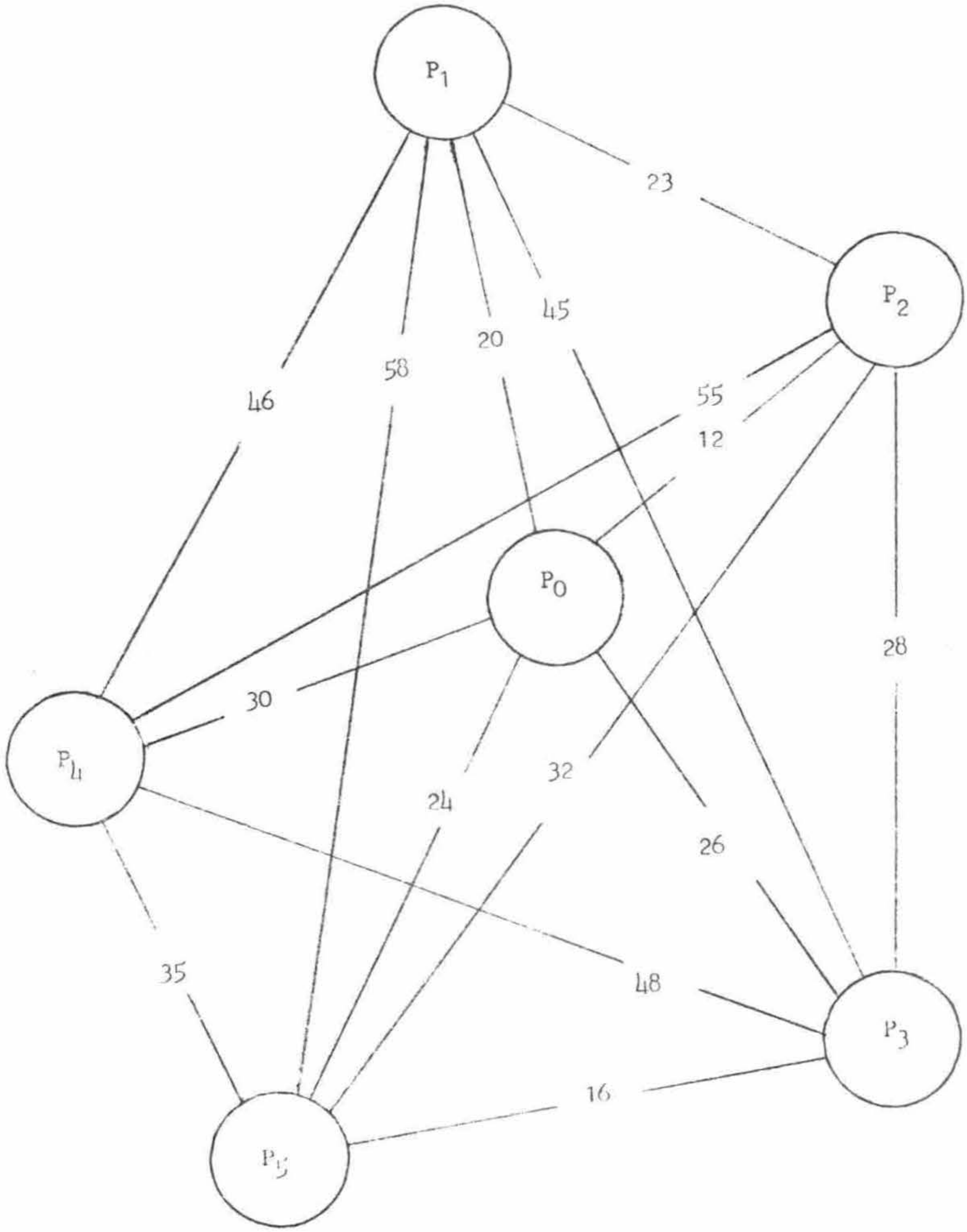


Figure 9. Location and distance map for Problem 2

to be calculated. See Tables 3 and 4. The total number of possible pairs is equal to $\frac{N!}{2!\ (N-2)!} = \frac{5!}{2!\ (5-2)!} = 10$ pairs.

The first step is to examine the list of quantities to be delivered and to determine if any customer requires a quantity equal to or greater than the largest truck available. If so, that truck is assigned to that stop. P_3 has ordered 12 tons; therefore, truck A is assigned to that delivery point. The quantity ordered by P_3 is now 12 - 10 = 2 tons. One route has been determined as $P_0P_3P_0$. The order list now reads P_1 - 4 tons, P_2 - 4 tons, P_3 - 2 tons, P_4 - 6 tons, and P_5 - 3 tons.

The Lockset Method now examines the pairs from the largest DSC to the smallest DSC. The pairs are either locked in a route or locked out of a route subject to the following 4 tests.

1. Each stop must have at least one leg connected with the origin.
2. Each stop must previously have been on a different route.
3. A truck of sufficient size must be available to carry the combined load.
4. A truck capable of traveling the required distance must be available.

P_3P_5 is the pair with the largest DSC, and the pair meets all 4 tests. A truck is then assigned to a tentative route of $P_0P_3P_5P_0$. The route can be handled in either direction. The next largest DSC is for pair P_4P_5. Aggregation of P_4 to the tentative route of $P_0P_3P_5P_0$ would violate test 3, the capacity

Table 3. Distance matrix for Problem 2 in minutes

To	From P_0	P_1	P_2	P_3	P_4
P_1	20				
P_2	12	25			
P_3	26	45	28		
P_4	30	52	55	48	
P_5	24	58	32	16	35

Table 4. Pair list and distance saved coefficient for Problem 2 in minutes

P_i-P_j	P_oP_i	P_oP_j	P_iP_j	DSC_{ij}
P_1-P_2	20	12	25	7
P_1-P_3	20	26	45	1
P_1-P_4	20	30	46	4
P_1-P_5	20	24	58	-4
P_2-P_3	12	26	28	10
P_2-P_4	12	30	55	-13
P_2-P_5	12	24	32	4
P_3-P_4	26	30	48	8
P_3-P_5	26	24	16	34
P_4-P_5	24	24	35	13

level of the trucks, thus P_4P_5 is locked out of the route. Pair P_2P_3 has the next largest DSC, and the pair meets all the tests. The tentative route becomes $P_0P_5P_3P_2P_0$. Looking at the rest of the pairs shows that any pair will at least violate test 3, the truck capacity restriction; therefore, $P_0P_5P_3P_2P_0$ becomes a final route. A new route is developed with the next largest DSC.

Pair P_3P_4 is the first pair to consider. P_3 does not have at least one leg connected with the origin. Pair P_3P_4 fails to meet test 1. The joining of pair P_1P_2 fails to meet test 3, as shown in the previous paragraph.
The pair with the next largest DSC is pair P_1P_4. This pair meets all the tests and a truck is assigned to a tentative route of $P_0P_1P_4P_0$. The two customers, P_1 and P_4, fill the truck to capacity; therefore, the route is final.

All customers have been assigned to a route, therefore, the pairs of P_2P_5, P_1P_3, P_1P_5, and P_2P_4 will not have to be taken into consideration. Pairs P_1P_5 and P_2P_4 have negative DSC. It takes less time to handle the customers separately than if the pairs were combined on a route.

Table 5 gives the final solution as given by the Lockset Method. It should be noted that Lockset filled to capacity 2 out of the 3 trucks on the routes. The 120 minute time restriction did not affect the routes in this particular situation.

The above two problems have, hopefully, shown how the

Table 5. Final results for Problem 2

Route number	Sequence	Carrier	Capacity	Load	Distance
1	$P_0P_3P_0$	A	10	10	52
2	$P_0P_5P_3P_2P_0$	B	10	9	80
3	$P_0P_1P_4P_0$	C	10	10	106

basic Lockset Method is applied. Lockset has only been developed recently and has only been applied in a few areas, but it has shown potential. With Lockset, existing routes can be reorganized. In the reorganization of an area, new routes and the sequence of stops for each route are provided by Lockset. Lockset can also answer specific policy questions like: What size of truck to use? Should drivers work overtime? Should a new customer be added? What fee should be assessed for delivery or assembly services?

The following sections show previous studies and the routes developed by application of Lockset to the members of the Mid-America Dairymen, Inc. in the Twin Lakes, Minnestoa, area.

CHAPTER V. REVIEW OF THE LITERATURE

This section will review actual studies that used the Lockset Method and discuss the relation of the transportation model to the Lockset Method in the overall transportation problem.

Schruben and Clifton (19) pioneered the Lockset Method and applied it to the routing of feed delivery trucks. This study was an ex post examination of information gathered by Schruben and Clifton in a study of truck delivery costs (20). The Lockset process was developed and applied to the available information; information that was all available at the time that management made its original routing decisions.

Comparing the routes developed by Lockset with the actual routes used showed a 195 mile savings and 1 less truck used. The 195 miles was 10 percent of the total distance traveled. Schruben and Clifton applied Lockset to a total of 12 firms that delivered feed and the distance saved per firm varied from 8-12 percent. In a number of cases fewer trucks were also needed.

Hallberg and Gentry (6) have applied Lockset to designing efficient routing systems for retail milk delivery. The ten existing individual routes were separately reorganized. One route had a travel time saving of 14.7 percent. Four routes had travel time savings ranging from 1.4 percent to 3.6 percent. On four of the routes no travel time savings resulted from the reorganization. One route increased in total delivery time. With the ten individual reorganized routes the total milk on the routes could be delivered in 81 fewer minutes for each day of delivery.

The development of new routes involving the entire area, not considering existing individual routes, resulted in a 123 minute savings for each day of delivery. The reorganization also resulted in fewer trucks being needed. The annual costs per quart of milk delivered dropped from 8.87 cents to 5.92 cents.

Johnstone and Krieble (11), with cooperation of a dairy in Pennsylvania, applied Lockset to the routing of bulk trucks among dairy farmers for milk assembly. The total miles driven declined from 1,907 on the original routes to 1,696 on the reorganized routes. The reorganization showed a total mileage savings of 12.1 percent. The number of routes needed declined from the original 32 to 28, a 12.5 percent savings.

Hallberg (5) applied Lockset to a wholesale food distributor, serving primarily institutions in a large metropolitan area. In addition to the routing procedure, this application of Lockset answers various policy questions. Lockset showed that delivery costs could be reduced by increasing the amount of time drivers could be on the road. Lockset also showed that the result of meeting customers' delivery schedule requirements increased the delivery costs. When the schedule requirements could be relaxed, delivery costs could be reduced.

Use of Lockset in designing efficient delivery and/or pickup routes solves only a small part of the whole transportation problem. The Stollsteimer model (22) is one type of spatial model. Basically it takes I sources of one raw material and J possible plant sites and determines the number, size, and location of plants to be built, the amount to be processed in each plant, and the amount to be shipped from each origin to each plant in order to minimize total costs of assembling and processing the raw materials. Stollsteimer differs from Lockset in that the Stollsteimer model decides to what area a given product will be shipped whereas Lockset takes an area with given marketing patterns and hopefully develops a more economical routing process within the area.

The basic transportation model is a special kind of linear program. It is used most frequently in problems involving minimizing transport cost. The problem consists of having I different supply points, each of which can ship some homogeneous product to any one of J demand points. Each supply point has a known supply and each demand point has a known demand. The objective of the transportation model is to minimize transport costs.

Lockset is very similar to this basic transportation problem. Lockset takes J different supply points, each with a known supply of a homogeneous product, and tries to minimize transport cost to one demand point. The main difference is that Lockset can handle only one demand point, while the transportation model can handle J demand points. Milk producers are our supply points, and they along with the milk plant want to minimize transport costs.

Points of similarity among all three models are that they all involve space in an essential way. Cost minimization is the underlying factor behind them all. Lockset has an advantage in that it can be used by existing firms to improve their efficiency without looking at a complete reorganization of the total marketing procedure in the area.

CHAPTER VI. DATA

The data needed for this routing study includes:

1. The location of the milk plant to which all milk is hauled.
2. The location of each milk producer.
3. The distance between the milk plant and each milk producer.
4. The distance between each individual pair of milk producers.
5. The quantity of milk picked up from each milk producer.
6. The capacities of available trucks.
7. The restrictions impeding the routing procedure.
8. The stop time at each milk producer.
9. The existing routes for comparison.
10. A conversion figure changing miles into cost.

The data corresponding to numbers 1, 2, 5-7, and 9 were supplied by Mid-America Dairymen, Inc. offices in Des Moines, Iowa, and Twin Lakes, Minnesota. We calculated the data corresponding to numbers 3 and 4. Data under numbers 8 and 10 are from a least cost milk assembly study by Roof and Tucker (18). The following is the procedure in which the data were transformed and compiled into a workable form for Lockset.

Location Data

The Twin Lakes, Minnesota, area was studied under the assumption that all milk produced by members went to a milk plant in Twin Lakes. A map was provided showing the location of each milk producer in the area. Given these locations, the distance between each pair of milk producers and the distance between each individual producer and the milk plant was calculated.

Distance Data

All locations were plotted on county highway maps with a scale of one-half inch to one mile. To calculate the distances, the following procedure was used. A transparent grid was placed over the map. The production area can then be taken as lying in the first quadrant of a rectangular coordinate system. The abscissa would be running in a east-west direction and the ordinate in a north-south direction.

From the county maps, the coordinates were tabulated for the one milk plant and for the 193 milk producers. This measurement is accurate to within less than one mile.

A computer program was written to calculate the road distance between every pair of points. See Appendix 1 for the complete program. The calculation was made by finding the absolute difference between the X coordinates of the two points and adding that to the absolute difference between the

Y coordinates of the two points.

With all distances calculated, a mileage matrix can be formed. The mileage matrix is essential to Lockset because of its use in the calculation of the distance saved coefficient.

The number of possible pairs is equal to $\frac{N!}{2!\ (N-2)!}$. For Grade A producers, the number of possible pairs is equal to $\frac{129!}{2!\ (129-2)!} = 8{,}256$ pairs. For Manufacturing grade producers, the number of possible pairs is equal to $\frac{64!}{2!\ (64-2)!} = 2{,}016$ pairs.

In going between the milk plant and the milk producers and between every pair of producers, the trucks are assumed to travel in a north-south direction and an east-west direction. The trucks may not travel in a diagonal direction. As a result of this assumption, errors in calculations can arise if some roads follow the landscape in a diagonal fashion. Diagonal roads would tend to make the actual mileage less than the estimated mileage. Many roads would also traverse hills which would make actual mileage greater than the estimated mileage.

Iowa and southern Minnesota tend to have predominantly a rectangular road system making diagonal roads a minor problem. The road distance calculation measures the abscissa (roads running east and west) and the ordinate (roads running north and south), not diagonal roads. The area covered in this study is also small enough that the earth's curvature will not distort the mileage to any significant effect. In this study, errors from diagonal roads, the landscape, and the earth's curvature are assumed to balance each other out. In most cases the actual calculation error will be small. No map errors nor measurement errors are assumed to exist in this study.

Quantity Data

The quantity of milk collected from each producer and the number of times milk was collected from each producer in the month of September, 1972, was supplied by Mid-America Dairymen, Inc. From this, the average pounds per pick up for each producer was calculated.

September is typically a low production month, therefore any routes calculated for September's pick up might be inappropriate in months of higher production. Because of this, September's production figures were adjusted to a peak month's production. The month of June was chosen as the month with the highest production level.

To make this adjustment the average pounds per pick up in September was multiplied by 1.31 for Grade A producers and 1.59 for Manufacturing grade producers. The conversion figures were derived by Mid-America Dairymen and represent June's total milk production in the Twin Lakes area for Grade A and Manufacturing grade routes relative to September's production.

To try and compensate for days when the quantity of milk collected is greater than the average daily collection, the quantity of milk received per producer was further adjusted to reflect daily milk production above the daily average production for the month of June.

The conversion figures were calculated from daily total route collections figures. The quantity of milk corresponding to the 75th percentile of daily total route quantities was divided by the average daily quantity of milk to determine the conversion figures. In a month with 30 collection days, the 75th percentile would represent the 7th largest daily quantity of milk collected.

In Grade A Route 510 the quantity of milk corresponding to the 7th largest day in September is 19,889 pounds. The average quantity of milk collected is 19,226 pounds. Completing the division determines the 1.03 conversion figure.

The average daily June quantity figures were adjusted by the following: Route 510 - 1.03, Route 511 - 1.23, Route 513 - 1.24, Route 521 - 1.3, Route 522 - 1.15, Route 523 - 1.02, Route 572 - 1.35, Route 573 - 1.1, Route 577 - 1.23, Route 578 - 1.58.

Truck Data

The Twin Lakes, Minnesota, area has contract haulers. The milk plant has no authority over the routes; either in their establishment or in forcing changes in the routes.

Contract haulers provide their own trucks. The truck capacities vary in size, as would be the case in most situations. The truck capacities for Grade A and Manufacturing grade routes are shown in Tables 6 and 7. The 2,000 gallon truck is the most common.

Most of the milk picked up in the Twin Lakes area is on an alternate day collection. Since the supply of milk available from each producer was determined from an alternative day pick up, the maximum number of trucks required to assemble the milk will be equal to one-half the number of routes. In certain cases the number of trucks might be smaller because the routes might not take all day. One truck might handle two or more routes in one day.

At the present time in the Twin Lakes area, several trucks require two or more trips to the milk plant for completion of their route.

Restrictions

Restrictions are problems that contract haulers and the milk plant face in setting up the routes for the milk collection. Restrictions usually hinder mile-saving reorganizations. Examples are the limits on the working of overtime and individual producer restrictions. Producer restrictions would include different loading facilities the trucks must face, and a set time during the day in which the trucks are allowed to pick up the milk. These restrictions are usually faced by the contract haulers, not the milk plant.

One restriction faced by both the milk plant and the

Table 6. Grade A routes - truck capacities

Route number	Capacity: Gallons	Capacity: Pounds[a]
510	2,000	17,220
511	2,000	17,220
513	2,300	19,803
521	1,700	14,637
522	3,250	27,982
523	2,100	18,089

[a]Grade A milk was figured at 8.61 pounds per gallon.

Table 7. Manufacturing grade routes - truck capacities

Route number	Capacity: Gallons	Capacity: Pounds[a]
572	2,000	17,220
573	2,000	17,220
577	2,100	18.089
578	1,700	14,637

[a]Manufacturing grade milk was figured at 8.61 pounds per gallon.

contract haulers arises from road embargoes and bridge weight limits. Minnesota and Iowa have road embargoes in the spring when the roads are soft and muddy, but since our routes will be developed for June the spring road embargoes will not be considered. Minnesota and Iowa do have 18,000 pounds road weight limits per axle. The road weight limit considers both front and rear axles. In Iowa there is a 3 percent tolerance level.

Bridges can be considered after Lockset has developed the routes. In most cases, alternative routes involving similar mileage exists between two producers. Bridge limits can be avoided by choosing the route without the bridge that has a weight limit. Bridges that can't be escaped will be detoured around.

Lockset does not consider restrictions unless the restrictions are programmed into the procedure. If management develops the routes then they must consider the restrictions to be faced by the contract haulers. If not, the contract haulers must develop their own routes.

Cost Data

A cost study of Roof and Tucker (18) will be used to convert the mile savings into cost terms. Roof and Tucker determined that in Indiana the total transport cost for a 2,500 gallon truck was 20.8 cents per mile. This transportation cost included variable costs, fixed costs, and labor costs.

The 20.8 cents per mile transportation cost considers only travel time on the road not stop time at each producer.

Time Data

Since the routes are not company owned but owned by the contract haulers, time is not a restriction. Time is important in the paying of overtime. With contract haulers overtime is not a problem.

Time consists of two parts, travel time on the road and stop time at each producer. An Indiana study by Roof and Tucker (18) estimated that the average time per stop was 10 minutes and the average time per unit of distance was 1.8 minutes per mile. The weighted average speed of the trucks was 33.3 miles per hour.

Existing Route Data

The existing routes are needed for comparison with the routes developed by Lockset. Both Grade A and Manufacturing grade routes will be designed. The factor for comparison will be total miles traveled per route. See Tables 8 and 9 for the miles traveled per route.

After each individual existing route is reorganized, the entire area will be organized into totally new routes. The total miles traveled will again be the comparing factor. Lockset will try to find the optimal routing solution, considering all the options available to the Lockset Method.

Table 8. Existing Grade A routes

Route number	Number of producers	Total pounds collected	Truck capacity[a]	Miles traveled[b]
510	16	41,201	17,220	175
511	30	79,109	17,220	360
513	30	104,143	19,803	529
521	5	12,444	14,637	140
522	33	86,177	27.892	280
523	16	40,412	18,089	136
Total		363,486		1,620

[a]Listed in pounds.

[b]As reported by the truck drivers.

Table 9. Existing Manufacturing grade routes

Route number	Number of producers	Total pounds collected	Truck capacity[a]	Miles traveled[b]
572	16	33,551	17,220	145
573	21	60,941	17,220	181
577	12	27,291	18,089	97
578	15	43,094	14,637	150
Total		164,877		573

[a]Listed in pounds.

[b]As reported by the truck drivers.

CHAPTER VII. RESULTS

Lockset was at first used to reorganize each individual existing route. Grade A routes and Manufacturing grade routes are handled separately.

Reorganization of Existing Routes

Throughout the results section, numerous references will be made to routes and to trips. A route is comprised of all the producers handled by a driver. A trip refers to the number of times a truck must be emptied to complete the pick up of all the milk on a route.

An existing route is the sequence of producers that was used to pick up the milk in September, 1972. Our routes are calculated for a peak production month, namely June. The jump in pounds of milk collected will increase the number of trips needed to complete the Lockset routes over the existing routes.

Grade A routes

Table 10 gives the sequence of producers as the milk was collected on existing routes. These sequences of producers were obtained by talking to the individual drivers of each route. The miles traveled as reported by the truck drivers and as determined by the computer using the coordinate data is listed for each trip. Table 11 presents the sequence of producers as determined by the Lockset Method. Listed with each trip is the miles traveled as calculated by Lockset and

Table 10. Sequence of producers for existing individual Grade A routes

Route	Trip	Sequence of producers	Miles traveled[a]	Miles traveled[b]
510	1	683-740-759-756-747-750-652-753-8-81-16-4-83-96-195-120	175	175
511	1	42-755-751-70-178-103-154-137-455-670-655-679-668-681-677-73	211	142
	2	528-847-850-524-566-554-540-418-455-416-401-42-71-69-167-692	149	178
513	1	629-615-623-632-992-980-997-893-971	125	115
	2	635-612-613-992-640-621-641-635-606-624-609-600-618-977-985-610	234	156
	3	970-972-974-975-982	170	149
521	1	902-901-786-965-960	140	122
522	1	769-760-770-761-766-248-215-232-218-335-311-353-389-325-214-201	145	166
	2	147-135-127-173-170-218-298-238-340-308-362-368-361-357-936-938-955	135	154
523	1	305-402-430-558-539-174-444-474-409-472-831-956-302	111	90
	2	413-467-438	25	18
Total			1,620	1,465

[a]Miles traveled as reported by the truck drivers.

[b]Miles traveled as determined by the computer.

Table 11. Sequence of producers for individual Grade A route reorganizations

Route	Trip	Sequence of producers	Miles traveled[a]	Percentage of truck capacity used
510	1	195-120-4-83	54	46.9
	2	8-952-683-81-16	103	92.5
	3	759-740-756-750-753-749-96	90	99.7
511	1	524-528-73-167-69-70-103	79	94.5
	2	418-401-416-137-154-178	36	96.0
	3	850-847-554-566-455	56	73.0
	4	540-692-71-42-751-755	82	98.8
	5	670-655-668-679-681-677	83	96.9
513	1	982-983-612-618-600-615	103	99.4
	2	623-632-624-613-641-606	90	98.4
	3	985-609-976-977-610-629	84	93.9
	4	997-980-992-640-621	110	96.3
	5	635	54	47.0
	6	970-974-975-972-971	134	90.6

[a]As determined by the computer.

Table 11. (Continued)

Route	Trip	Sequence of producers	Miles traveled[a]	Percentage of truck capacity used
521	1	965-786-901-902-960	113	85.0
522	1	389-214-201-218-135-173-170-127-147-298	58	95.8
	2	353-311	9	15.5
	3	325-340-238-766-770-761-760-769-215-231-232	87	99.8
	4	955-936-938-357-361-368-362-335-309-248	35	76.7
523	1	413-467-474-305	20	54.0
	2	558-539-174-444-438-430-402	59	95.4
	3	956-831-472-409-302	32	73.8
			1,571	83.63

the percent of capacity each trip filled the trucks. The Lockset Method filled the trucks to an average of 83.63 percent of capacity.

Figures 10-15 are maps of the Grade A routes determined by Lockset. The maps show the production area involved and the trips to complete each route. In both the tables and the maps, the producers are denoted by the particular producer number assigned to them.

Table 12 compares the routes developed by the Lockset Method to the existing Grade A routes. The miles traveled to complete the route will be the comparison factor. The mileage as reported by the truck drivers and as determined by the computer will both be involved in a comparison with Lockset. The mileage differences for each individual route can be seen in Table 12.

On the existing routes a total of 1,620 miles were driven as reported by the truck drivers. Lockset, by reorganizing each individual Grade A route, collected the milk by traveling 1,571 miles. This 49 mile decrease is a 3.0 percent change amounting to a $10.19 cost savings per collection period. A figure of 20.8 cents per mile (18) was used to determine cost savings. The cost savings represents the amount of money that could be saved by Lockset per milk collection period. In our study the collection period was 2 days. In an area where the milk is collected on an every other day basis, the collection period spans two days.

Figure 10. Grade A Route 510 reorganization

Figures 10-19 will use the following Legend:

Trip 1 ————————————

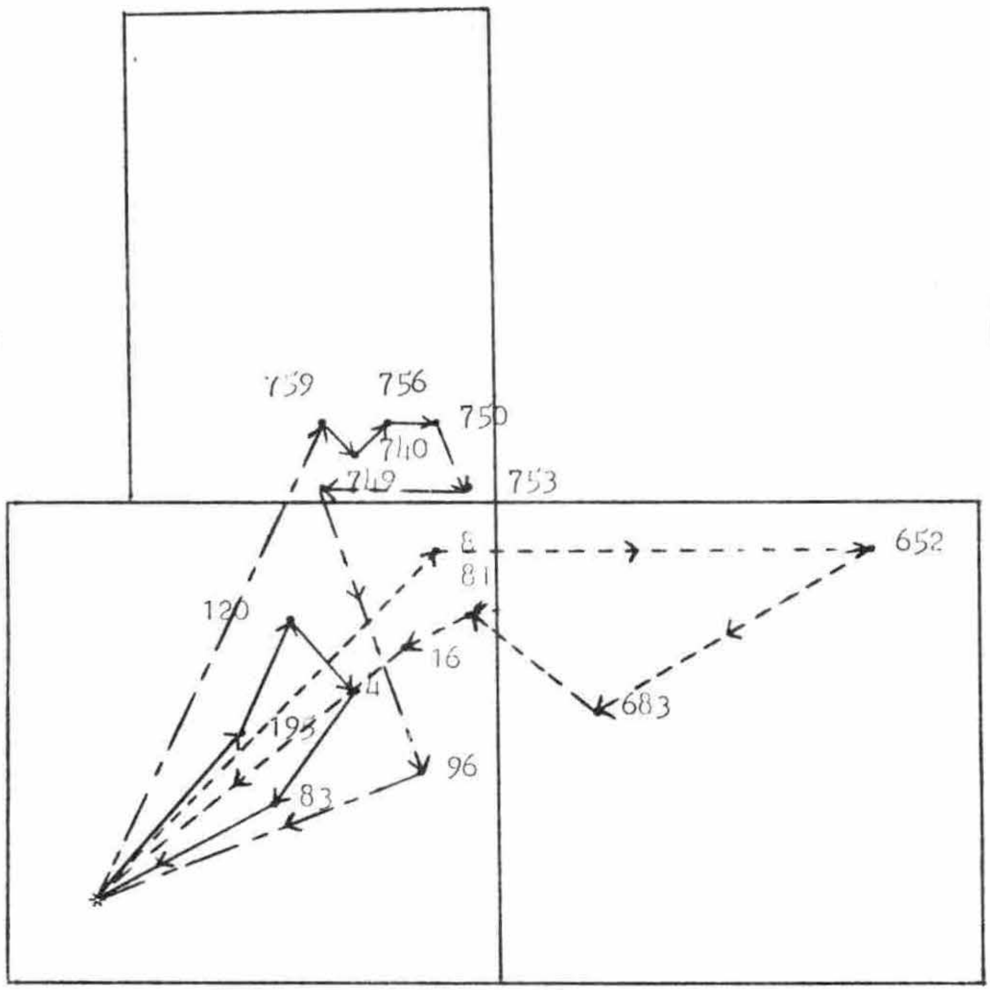
Trip 2 ----------------------

Trip 3 — - — - — - — - —

Trip 4 — - - — - - — - - —

Trip 5 — — — — — — — —

Trip 6 ....


759
756
750
740
749
753
8
652
81
120
16
4
683
193
96
83

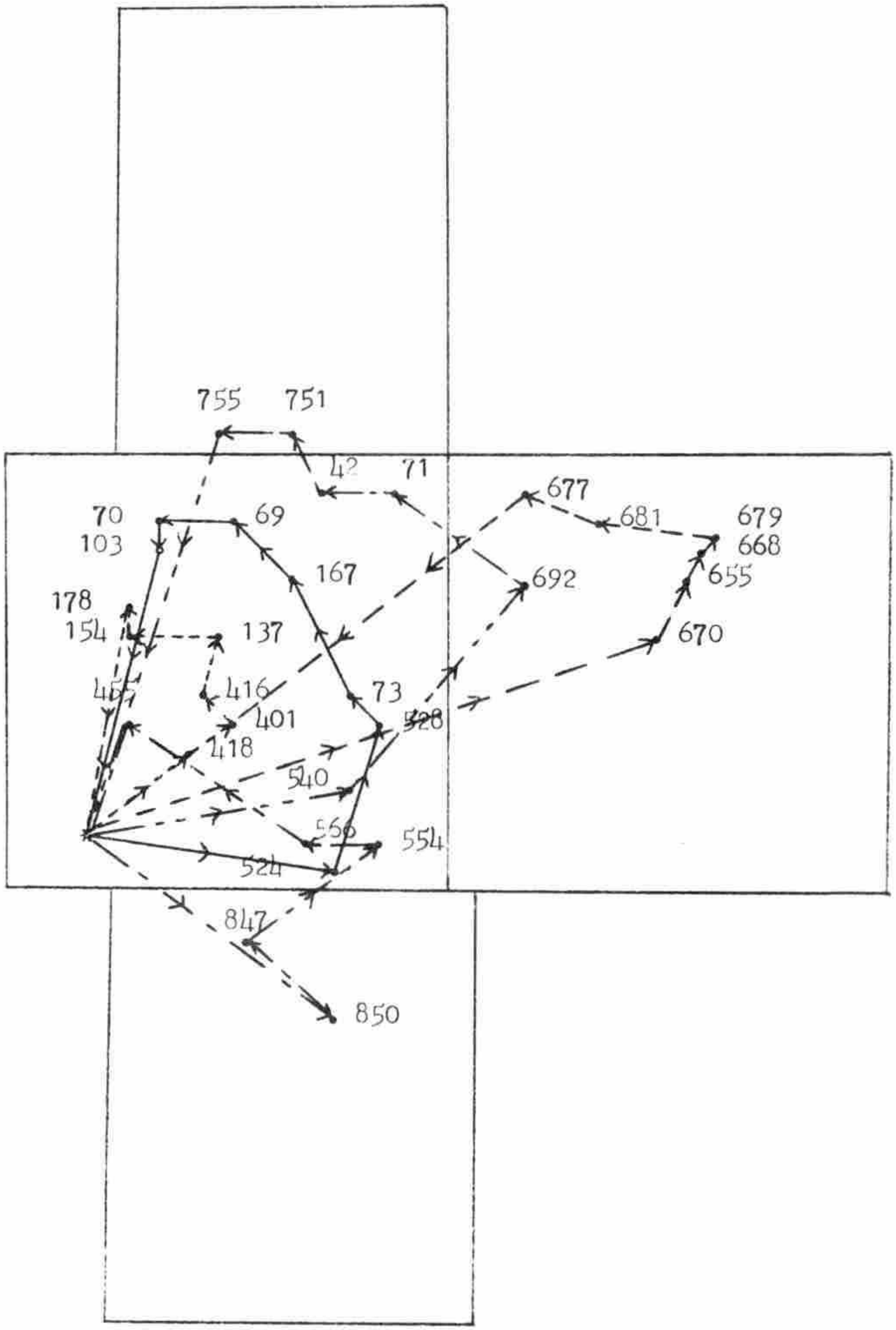


Figure 11. Grade A Route 511 reorganization

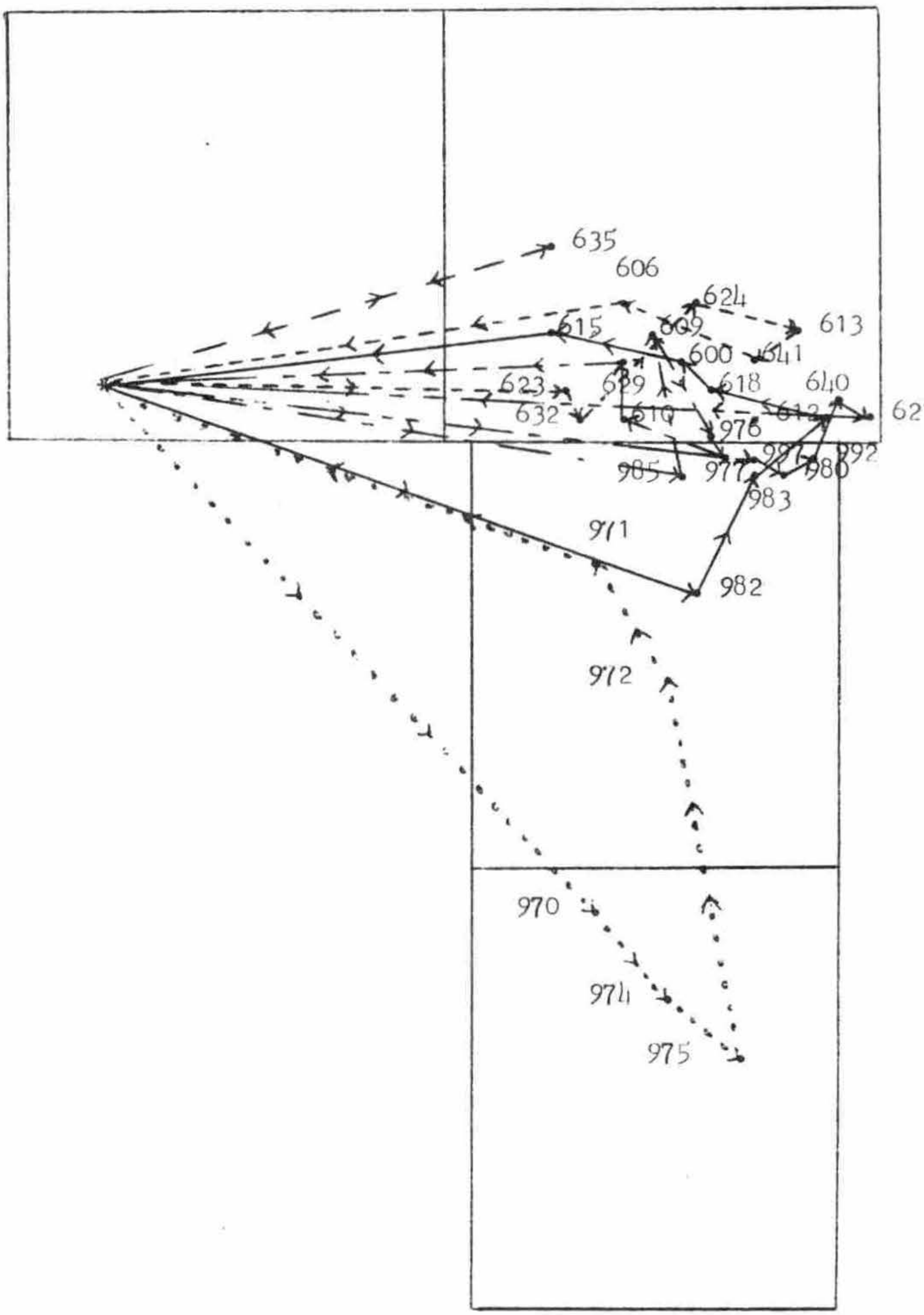


Figure 12. Grade A Route 513 reorganization

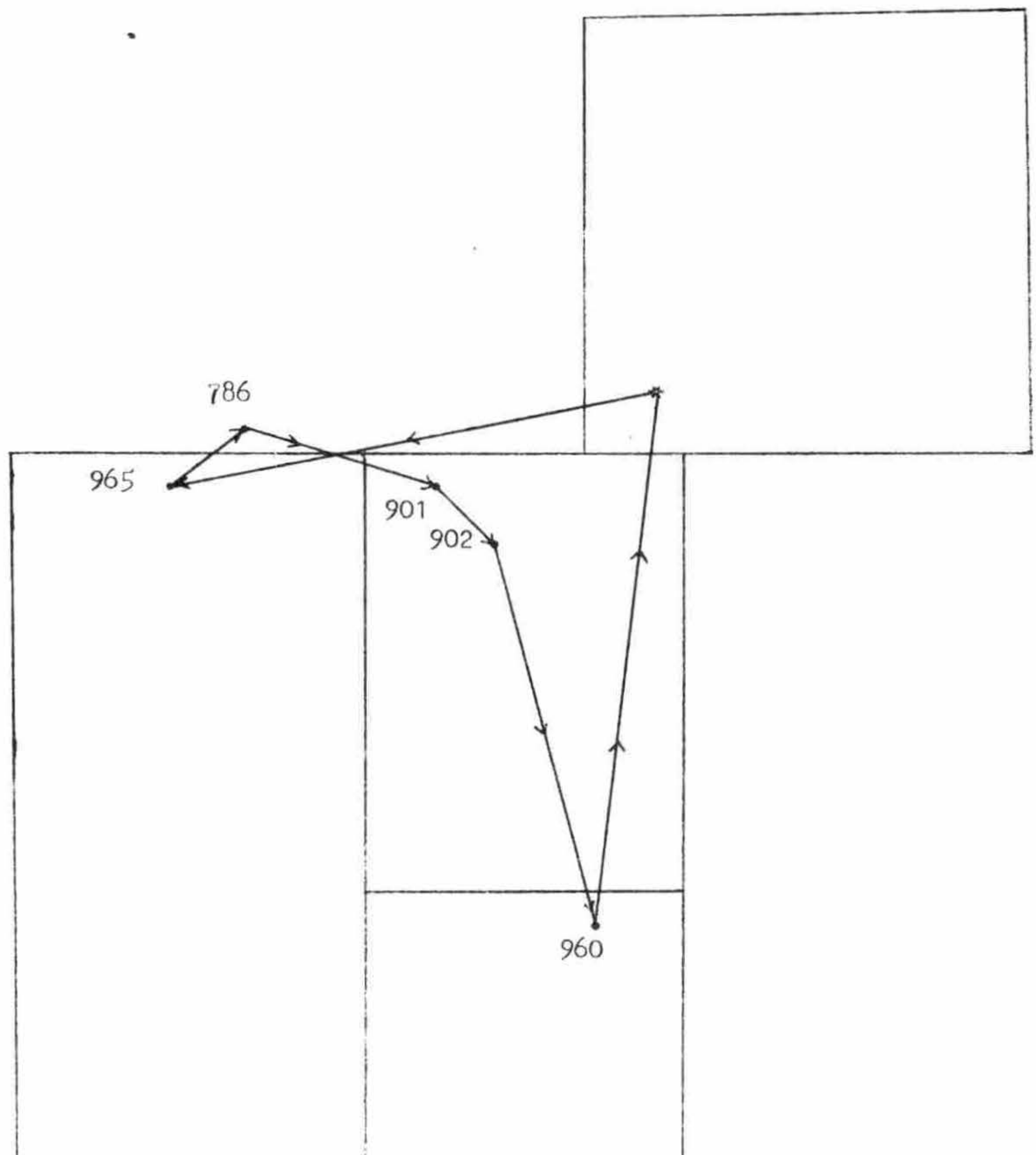


Figure 13. Grade A Route 521 reorganization

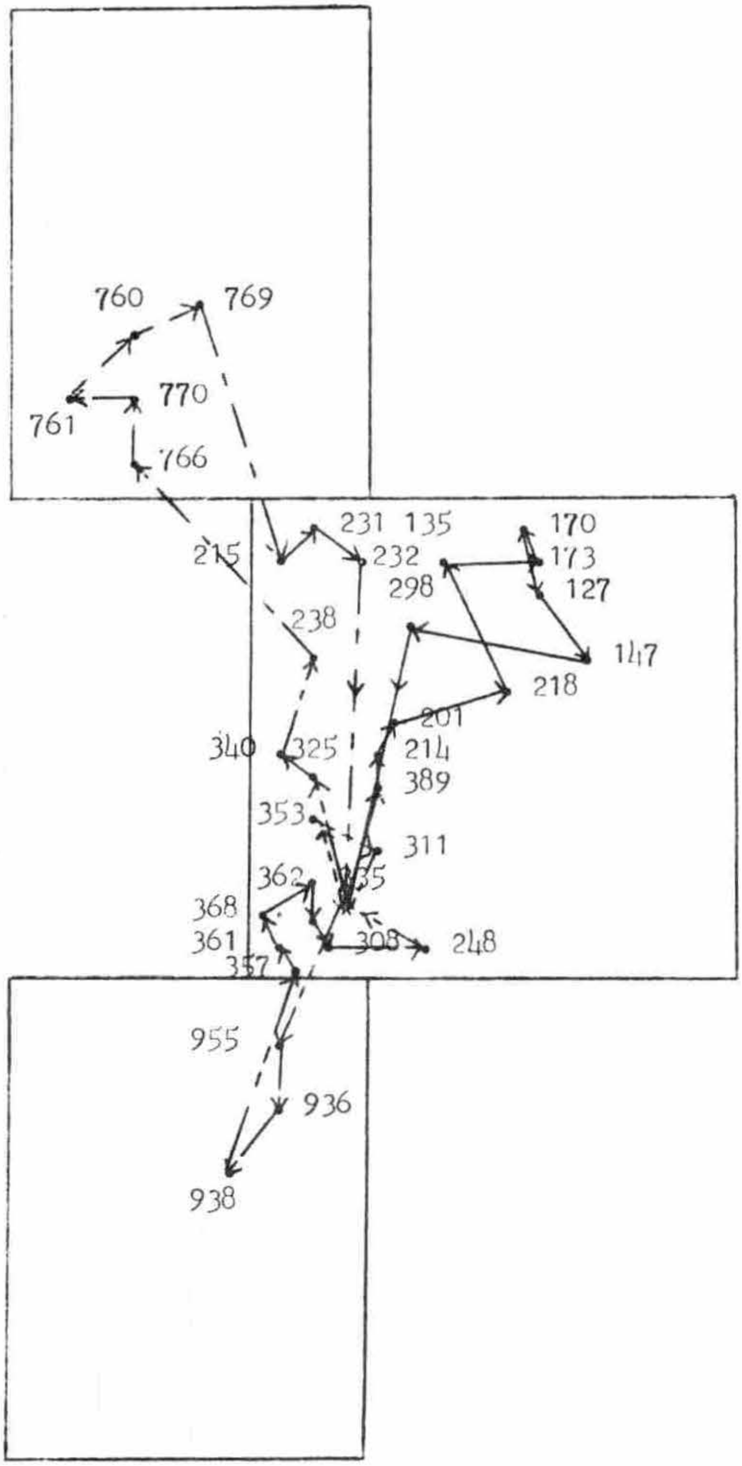


Figure 14. Grade A Route 522 reorganization

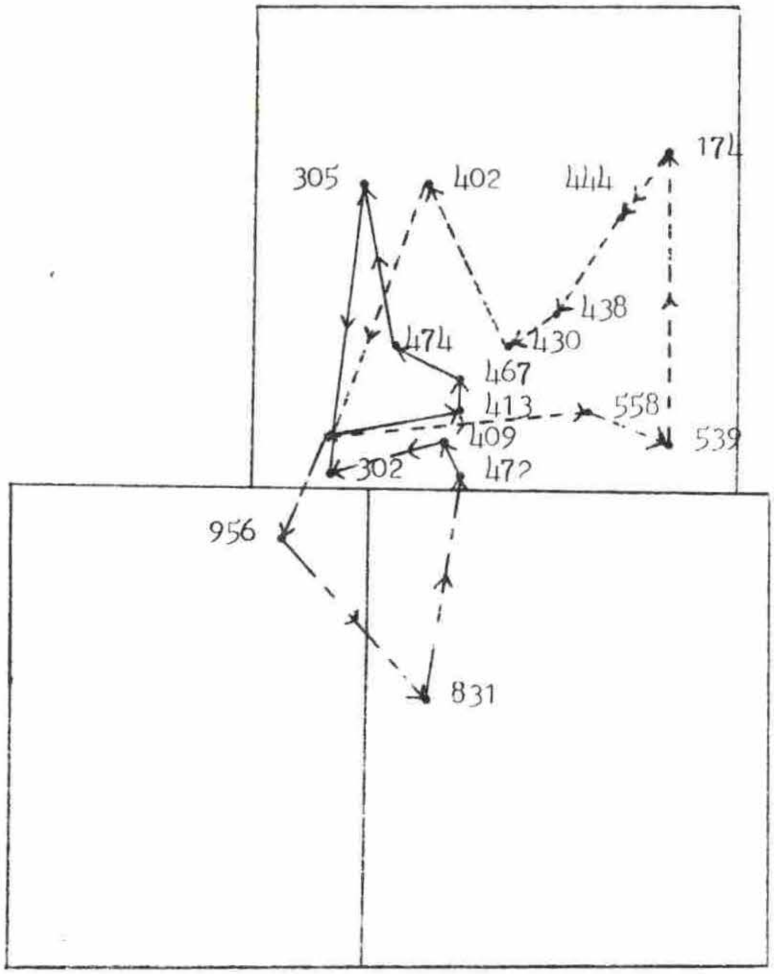


Figure 15. Grade A Route 523 reorganization

Table 12. Comparison of existing Grade A routes and Lockset developed routes

Route number	Existing mileage		Lockset mileage	Mileage saved[a]	
	Driver[e]	Computer[f]		Driver[e]	Computer[f]
510	175	175	247	-72	-72
511	360	320	336	+24	-16
513	529	420	575	-46	-155
521	140	122	113	+27	+9
522	280	320	189	+91	+131
523	136	108	111	+25	-3
	1,620	1,465	1,571	+49	-106

[a]Existing mileage - Lockset mileage.

[b]Equal 0 if existing mileage - Lockset mileage < 0; equal existing mileage - Lockset mileage if existing mileage - Lockset mileage $\geq$ 0.

[c]Assuming 20.8 cents per mile cost.

[d]Refer to Table 8 for total pounds collected per route.

[e]Miles traveled as reported by the truck driver.

[f]Miles traveled as determined by the computer.

Improvement by Lockset					
Miles[b]		Cost Savings[c]		Cost savings/cwt[d]	
Driver[e]	Computer[f]	Driver[e]	Computer[f]	Driver[e]	Computer[f]
0	0	0.0	0.0	0.0	0.0
24	0	4.99	0.0	0.006	0.0
0	0	0.0	0.0	0.0	0.0
27	9	5.61	1.87	0.045	0.015
91	131	18.93	27.24	0.022	0.032
25	0	5.20	0.0	0.013	0.0
167	140	$34.73	$27.11	$0.086	$0.047

Most of the milk in the Twin Lakes area is picked up on an every other day basis. On routes with two or more trips, one or more trips are handled one day with the remaining trips handled the next day. The truck drivers select the trips by trying to keep the number of producers collected daily fairly even.

When comparing the mileage as determined by the computer to the Lockset mileage, the result is a 106 mile increase by Lockset.

When looking at just the routes where Lockset made improvement, 167 miles were saved over the existing mileage as reported by the truck drivers. The total cost savings on the four Grade A routes in which Lockset made improvement was $34.73. The cost savings per hundredweight of milk collected is 8.6 cents. In practical applications of Lockset, where Lockset fails to improve mileage on the existing routes, they can continue to be used. For example, Grade A Route 510 showed a 72 mile increase from Lockset, therefore the improvement by Lockset would be zero miles.

Making the same comparisons using the existing mileages as determined by the computer shows that Lockset made a 140 mile improvement on two routes. The cost savings is $29.11 per collection period. The per hundredweight cost savings of milk collected is 4.7 cents.

Several of the trips shown in the figures have kinks in the routing. These kinks are as Lockset developed the routes.

In Figure 12, Grade A Route 513-Trip 3 has a kink. The mileage with the kink is 84 miles and without the kink is 87 miles. Grade A Route 521 in Figure 13 is one mile longer with than without a kink. Trips 1 and 4 in Grade A Route 522 have kinks as shown in Figure 14. Without the kinks, mileage is increased by 6 miles on Trip 1 and by 24 miles on Trip 4. Determining the routes without kinks was done by visual appraisal.

Manufacturing grade routes

Table 13 shows the sequence of producers for the existing individual Manufacturing grade milk routes. The truck drivers reported the sequence and the corresponding mileages. Also listed is the mileage as calculated by using the coordinate data. Table 14 gives the sequence of producers as calculated by the Lockset Method. Along with the sequence of producers is the Lockset determined mileage on each trip and the percent of capacity used on each truck per trip. The trucks were filled to an average of 82.78 percent of capacity.

Figures 16-19 are maps of Lockset's reorganized manufacturing routes. Each map displays how the milk was picked up. In both the tables and the maps, the producers are designated by a particular producer number assigned to them.

Table 15 compares the existing Manufacturing grade routes to the routes developed by Lockset. The Lockset mileage will be compared to both the truck driver reported mileage and the

Table 13. Sequence of producers for existing individual Manufacturing grade routes

Route	Trip	Sequence of producers	Miles traveled[a]	Miles traveled[b]
572	1	72-77-3-41-78-86-74-82-699-676-658-18-660-605-527-421	145	131
573	1	897-542-581-537-507-459-560-552-579-576-571-422	86	92
	2	891-888-841-862-839-802-891-414-887-869	95	106
577	1	431-141-112-177-222-296-280-269-373-315-453-492	97	65
578	1	942-940-951-944-929-947-954-941-952-856-854-874-906-925-908	150	134
			573	528

[a]Miles traveled as reported by the truck drivers.

[b]Miles traveled as determined by the computer.

Table 14. Sequence of producers for individual Manufacturing grade route reorganizations

Route	Trip	Sequence of producers	Miles traveled[a]	Percentage of truck capacity used
572	1	74-82-699-676-658-18-3-41	84	96.9
	2	605-527-660-78-86-77-72-421	90	97.8
573	1	581-576-579-552-560-414	43	80.0
	2	459-571-507-537-422	40	92.5
	3	802-891-897-542	50	89.8
	4	841-888-839-869-862-887	53	91.4
577	1	431-141-112-222-296-269-280-177	55	96.3
	2	492-453-373-315	26	54.4
578	1	856-854-954-874	47	88.6
	2	906	34	19.2
	3	908-947-929-941-952	81	87.0
	4	942-944-951-940-925	67	99.4
			670	82.78

[a]As determined by the computer.

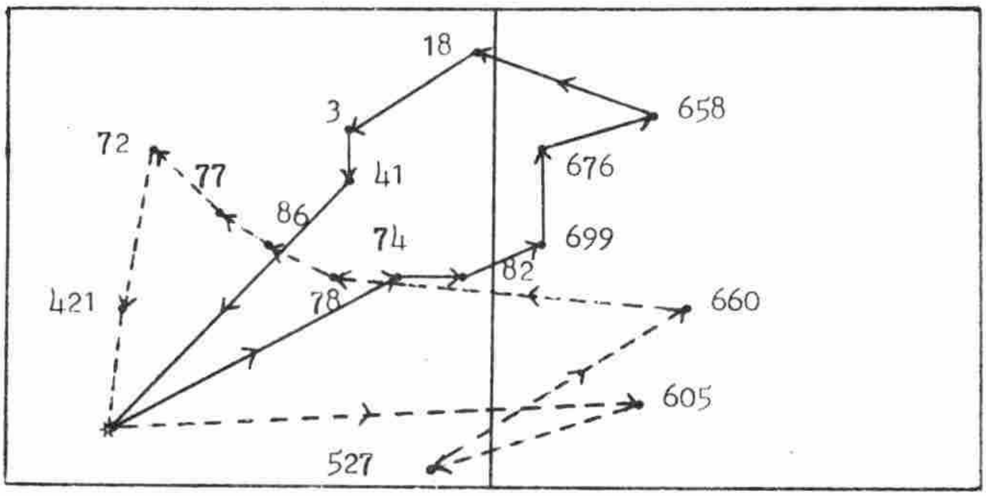


Figure 16. Manufacturing Route 572 reorganization

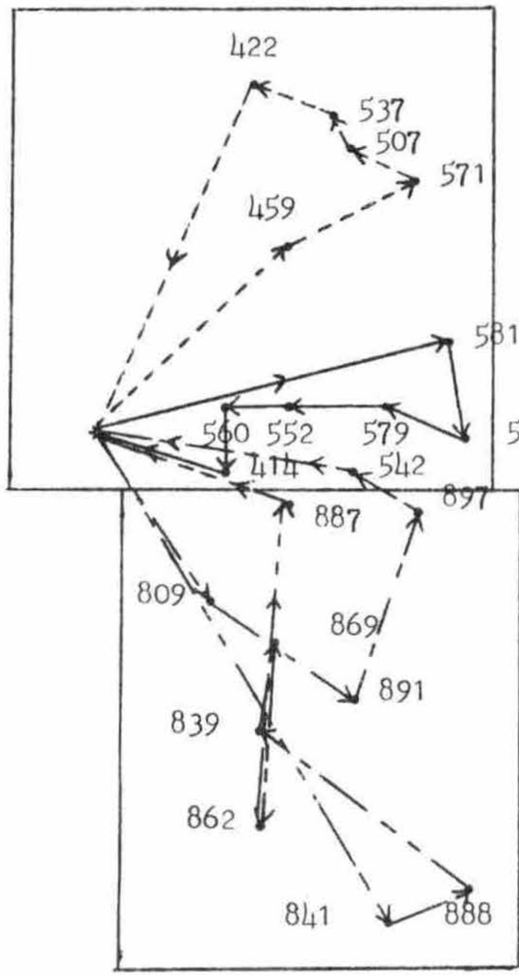


Figure 17. Manufacturing Route 573 reorganization

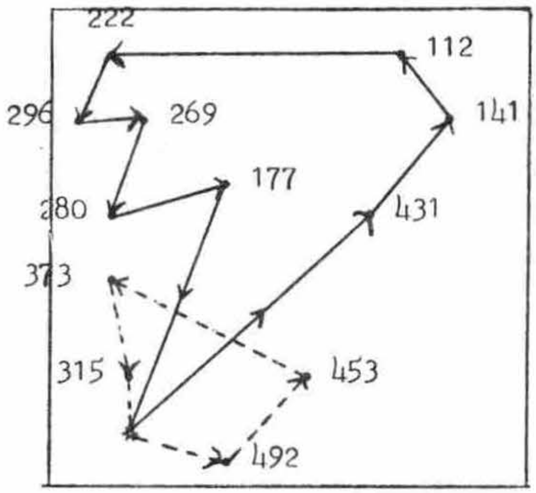


Figure 18. Manufacturing Route 577 reorganization

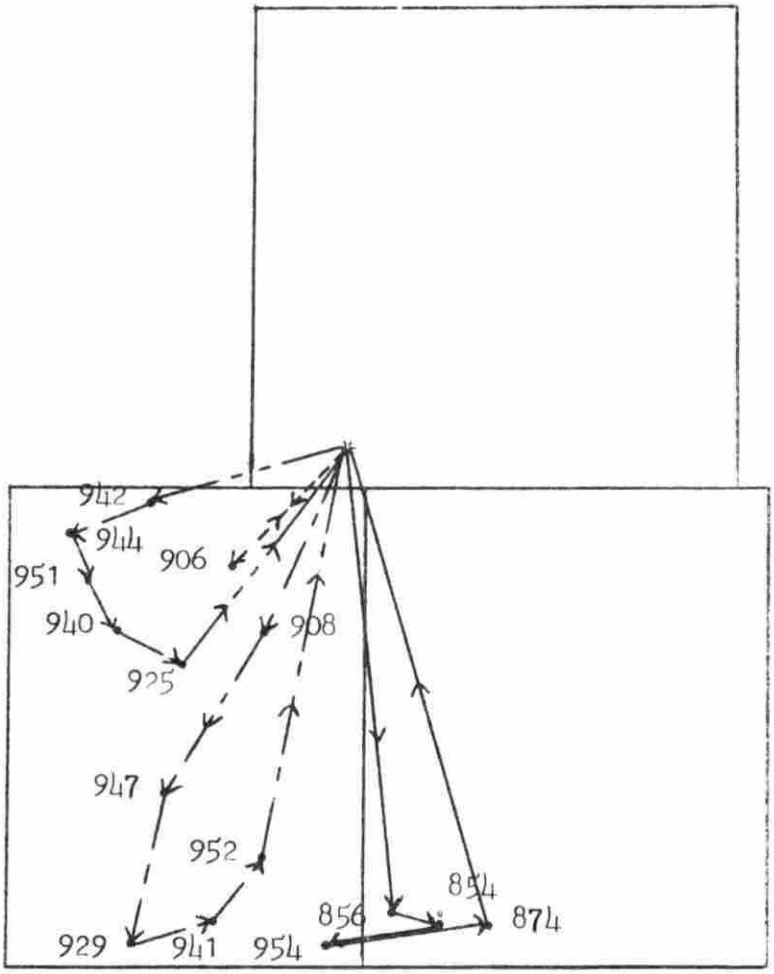


Figure 19. Manufacturing Route 578 reorganization

Table 15. Comparison of existing Manufacturing grade routes and Lockset developed routes

Route number	Existing mileage Driver[e]	Existing mileage Computer[f]	Lockset mileage	Mileage saved[a] Driver[e]	Mileage saved[a] Computer[f]
527	145	131	174	-29	-43
573	181	198	186	-5	+12
577	97	65	81	+16	-16
578	150	134	227	-79	-95
	573	528	670	-97	-142

[a]Existing mileage - Lockset mileage.

[b]Equal 0 if existing mileage - Lockset mileage < 0; equal existing mileage - Lockset mileage if existing mileage - Lockset mileage $\geq$ 0.

[c]Assuming 20.8 cents per mile cost.

[d]Refer to Table 9 for total pounds collected per route.

[e]Miles traveled as reported by the truck driver.

[f]Miles traveled as determined by the computer.

Improvement by Lockset					
Miles[b]		Cost savings[c]		Cost saving/cwt[d]	
Driver[e]	Computer[f]	Driver[e]	Computer[f]	Driver[e]	Computer[f]
0	0	0.0	0.0	0.0	0.0
0	12	0.0	2.50	0.0	0.004
16	0	3.33	0.0	0.012	0.0
0	0	0.0	0.0	0.0	0.0
16	12	$3.33	$2.50	$0.012	$0.004

computer determined mileage. Each mileage difference for the individual routes is shown in Table 15.

When comparing the total miles driven, Lockset increased the mileage of the Manufacturing grade routes by 94 miles over the mileage as reported by the truck drivers. In a comparison with the mileage as determined by the computer, Lockset increased the miles traveled by 142 miles.

When looking at the overall improvement by Lockset, one route made a 16 mile savings resulting in a $3.33 cost savings. The cost savings per hundredweight of milk collected is 1.2 cents. This comparison is between the Lockset mileage and the truck driver mileage. The overall improvement just looks at the routes where Lockset saved mileage.

In comparing the Lockset mileage and the computer mileage, Lockset had an overall improvement of 12 miles on one route. The $2.50 cost savings represents a .4 cent cost savings per hundredweight of milk collected. In practical applications of Lockset, where Lockset fails to improve mileage on the existing routes, they can continue to be used.

In Figure 16, Manufacturing grade Route 572-Trip 2, Lockset developed a kink. The kinked route is 90 miles, without the kink the route is 88 miles. Manufacturing grade Route 573-Trip 4 in Figure 17 has a kink. Drawing the route without the kink lengthens the route by 27 miles. Trip 1 for Manufacturing grade Route 578 in Figure 19 has a kink; eliminating the kink decreases mileage on the route by 1 mile.

Determining the routes with no kinks was done by visual appraisal.

Complete Reorganization of Entire Area

The problem analyzed here is to reorganize all milk producers into new routes without reference to the existing routes. Grade A and Manufacturing grade producers will be handled separately.

Grade A reorganization

Table 16 gives the sequence of producer stops that were developed by Lockset. As noted, a route is comprised of several trips. We did not assign a trip to any particular route. Also presented in Table 16 is the miles traveled as computed by Lockset for each trip and the percent of capacity filled on each trip. Lockset filled the trucks to an average of 93.9 percent of capacity.

The results of the entire area reorganization of Grade A producers are shown in Table 17. The truck drivers originally reported that the Grade A milk was picked up in 1,620 miles. Lockset collected the milk in 1,360 miles. The difference is 260 miles, which represents a 16.0 percent decrease.

The cost savings is $54.08 per collection period. Looking at an every other day collection period, over a year the cost savings would amount to $9,842.56. The cost savings per hundredweight of milk collected is 1.5 cents.

Table 16. Sequence of producers for each trip involved in the entire Grade A area reorganization

Trip	Sequence of producers	Miles traveled[a]	Percentage of truck capacity used
1	325-238-766-770-761-760-769-215	87	99.8
2	218-232-231-135-173-127-147	41	96.4
3	641-609-618-629-640-624-298	80	99.6
4	956-960-357-361-362-368-308	68	95.3
5	311-474-430-467-413	15	67.3
6	335-302-831-472-248-409	26	96.6
7	305-340-201-214-389-353	31	97.8
8	901-786-965-902-938-936-955	137	95.2
9	751-749-756-740-750-753-749-8	87	99.8
10	540-4-16-81-681-692-96	74	98.8
11	120-70-69-71-42-755-170	63	92.2
12	195-103-167-83-174-73-528-444	55	96.7
13	670-655-668-679-652-677-683	100	73.2
14	418-401-416-137-154-178-402	35	96.9
15	558-847-566-539-554-455-438	43	97.7
16	850-997-606-976-632-992-524	133	99.3
17	982-615-970-613-621-600-610	88	97.3
18	975-977-985-972-612-635	92	93.6
19	974-971-983-980-623	105	89.6
		1,360	93.9

[a]As determined by the computer.

Table 17. Entire area reorganization - Grade A producers

Miles traveled as reported by truck drivers	Miles traveled as determined by Lockset	Difference	% change	Cost savings[a]	Cost savings per cwt[b]
1,620	1,360	-260	-16.0	\$54.08	\$0.015

Miles traveled as determined by computer	Miles traveled as determined by Lockset	Difference	% change	Cost savings[a]	Cost savings per cwt[b]
1,465	1,360	-105	-7.2	\$21.84	\$0.006

Miles traveled as determined by individual Lockset reorganization	Miles traveled as determined by total Lockset reorganization	Difference	% change	Cost savings[a]	Cost savings per cwt[b]
1,571	1,360	-211	-13.4	\$43.88	\$0.012

[a]Assuming a 20.8 cents per mile cost.

[b]See Table 8 for total pounds of milk collected.

The miles traveled as determined by the computer to collect all the Grade A milk was 1,465 miles. When compared to Lockset routes, a 105 mile improvement was made by Lockset. The 7.2 percent improvement transfers into a $21.86 cost savings per collection period. The cost savings per hundredweight of milk collected is .6 cents.

When comparing the separate Grade A runs of Lockset, the entire area reorganization showed a 13.4 percent improvement over the individual route reorganization.

Manufacturing grade reorganization

Table 18 presents the results of the entire Manufacturing grade producers into totally new routes. Lockset increased the mileage by 55 miles over the truck driver's mileage. The cost of picking up the milk would increase by $11.44 per collection period.

Lockset increased the miles traveled when compared to the computer determined mileage by 100 miles.

When comparing the separate manufacturing runs of Lockset, the entire area reorganization showed a 6.2 percent improvement over the individual route reorganization.

The sequence of producers and trips involved in the completion of the routes are shown in Table 19. Also listed are the mileages on each trip and the percent of capacity filled on each truck. The trucks were filled to an average of 94.24 percent of capacity by Lockset.

Table 18. Entire area reorganization - Manufacturing grade producers

Miles traveled as reported by truck drivers	Miles traveled as determined by Lockset	Difference	% change	Cost savings[a]	Cost savings per cwt[b]
573	628	+55	+9.5	$11.44	$0.007

Miles traveled as determined by computer	Miles traveled as determined by Lockset	Difference	% change	Cost savings[a]	Cost savings per cwt[b]
528	628	+100	+18.9	$20.80	$0.013

Miles traveled as determined by individual Lockset reorganization	Miles traveled as determined by total Lockset reorganization	Difference	% change	Cost savings[a]	Cost savings per cwt[b]
670	628	-42	-6.2	$8.73	$0.005

[a]Assuming a 20.8 cents per mile cost.

[b]See Table 9 for total pounds of milk collected.

Table 19. Sequence of producers for each trip involved in the entire Manufacturing area reorganization

Trip	Sequence of producers	Miles traveled[a]	Percentage of truck capacity used
1	414-542-897-891-887	50	99.1
2	459-507-537-421-141-112	46	90.7
3	560-552-579-576-527-581-453	43	95.4
4	571-605-660-78-86-72-422	80	97.8
5	839-841-888-862-869-809	74	96.3
6	77-41-3-18-658-676-699-82-74	79	97.4
7	315-373-280-269-222-296-177-431	38	98.5
8	942-906-925-908-492	54	82.6
9	856-974-854-954-874	59	87.7
10	952-941-929-940-951-944	105	96.9
		628	94.24

[a]As determined by the computer.

CHAPTER VIII. CONCLUSIONS

The objective of this study was to determine if the Lockset Method could develop routes that could be implemented by Mid-America Dairymen, Inc. Realistic routes were designed, and mile savings existed over the base pick up period. In our various runs of Lockset, mileage was decreased on one-half of the routes. Lockset has potential.

Many problems were encountered. The period of analysis should immediately follow the base period being used for data collection. An immediate period of analysis eliminates the problem of new producers being added to the routes and the dropping of existing producers from the routes. It would also eliminate a memory gap in determining the existing routes. Improved accuracy should be the result of an immediate period of analysis.

The location of each producer and the distance matrix need to be well defined. In our coordinate measurement system, we measured to the nearest whole mile. Locating the producers to a fraction of a mile would improve accuracy and better define the calculation of the distance saved coefficient.

In the distance saved calculation, many pairs of producers had the same distance saved coefficient. Ties in the distance saved sometimes result in kinks in the routes. These kinks could often be removed by changing the storage order of two pairs of producers with the same distance saved coefficient.

By locating the producers more accurately, part of this problem can be eliminated.

Determining the existing routes for comparisons can be difficult if the milk was picked up by contract haulers, as was the case in the Twin Lakes area. After obtaining a new producer, Mid-America Dairymen, Inc. assign the producer to a particular route. Once on the route the driver picks up the milk according to his preference.

Problems to consider are that the drivers have no set order among the producers in collecting the milk. The drivers often have to drive past particular producers and return later because the producer hasn't finished milking. These problems can lead to inaccurate and varying mileages on the routes.

Drivers will interchange producers if it can be arranged. Grade A milk is picked up with Manufacturing grade milk if Grade A milk is being diverted. The interchanging of producers will lead to varying mileages.

The cost of obtaining solutions by the Lockset Method varies with the number of producers involved in the route development. The cost is related to the number of possible pairs of producers. A computer run involving 16 producers costs approximately $3.00; a run involving 64 producers costs approximately $10.00; and a run involving 129 producers costs approximately $35.00. This cost does not include a programmer's salary and noncomputation charges.

How did the Lockset Method fare? In our study we decreased the mileage on one-half of the routes programmed. Several of the routes came up with substantial savings. The entire area reorganization of Grade A producers come up with a cost savings per hundredweight of milk collected of 1.5 cents. This figure compares truck driver reported mileage to Lockset's mileage. In comparing the miles traveled as determined by computer to Lockset, the cost savings per hundredweight of milk collected is 0.6 cents. Lockset in the reorganization of all the Manufacturing grade producers increased the miles traveled to pick up the milk.

What is the solution? The answer is to use the routes developed by Lockset when they show the least amount of miles and to use the existing routes when they show the least amount of miles.

Is the Lockset Method ready for real world use? Yes, the potential is there. All that is needed is additional time and study with Lockset. I will leave this problem to the next researcher.

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APPENDIX A

This appendix contains the computer program used to calculate the mileage matrix and the distance saved coefficient. The program was written by Regis Rulifson.

The mileage matrix is the result of a technique developed by Halvorson (8). The technique measures a right angle distance between two points not a straight line distance. The absolute difference between the X coordinates and the absolute difference between the Y coordinates are added together to obtain the right angle distance. The calculation of the distance saved coefficient has been explained earlier in the MODEL DEVELOPMENT section.

The computer program in Figure 20 was written to give the distance saved coefficient as the final output.

```
      REAL COORD (195,2),DIST(4)
      INTEGER NUMBR(195)
      XORGN=34
      YORGN=33.5
      READ(5,1) (NUMBR(KK),(COORD(KK,LL),LL=1,2), KK=1,195)
  1   FORMAT (I4,2F5.2)
      DO 100 I=1,195
      Write (6,2) NUMBR(I),COORD(I,LO,COORD(I,2)
  2   FORMAT (LH1, 'DSC(I,J)',I6,'(',F5.2,',',F5.2,') TOX=')
      II=0
      DO 90 J=I, 195
      II=II+1
      DIST(II)+ABS(COORD)I,1)-COORD(J,1))+ABS(COORD(I,2)-COORD
                                                          (J,2))
      POPI=ABS(XORGN-COORD(I,1)+ABS(YORGN-COORD(I,2))
      POPJ=ABS(XORGN-COORD(J,1)+ABS(YORGN-COORD(J,2))
      DIST=(II)=POPI+POPJ-DIST(II)
      IF(II.GE.4.OR.J.GE.195)5OTO85
      GO TO 90
 85   WRITE(6,3)(NUMBR(J-I) I+M),COORD(N-I I+M,1),COORD(J-I
                                                       I+M,2),
    1              DIST(M),M=1,II)
  3   FORMAT(1H,4(2X,I6,'(',F5.2,',',F5.2,')=',F8.2))
 90   CONTINUE
100   CONTINUE
       STOP
       END
```

Figure 20. The computer program for calculating the mileage matrix and the distance saved coefficient

APPENDIX B

The computer program for the Lockset Method we used was developed at Pennslyvania State University by M. C. Hallberg and G. T. Gentry (6). Much thanks are given for allowing us to use the program.

The program was organized to fit our particular needs. All programming work was done by Regis Rulifson.

Because of the length of the computer program, it will not be included in this thesis. Dr. George W. Ladd, Department of Economics, Iowa State University, Ames, Iowa, 50010, will have a copy.